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April 26, 2019

Federal Express

Mr. Khai Dao
RCRA Project Manager
US Environmental Protection Agency
1650 Arch Street, Mailstop 3WC22
Philadelphia, PA 19013

RE: Cherokee Pharmaceuticals, LLC Fourth Quarter 2018 Comprehensive Groundwater Monitoring Results

Dear Mr. Dao:

Cherokee Pharmaceuticals LLC, a Subsidiary of Merck Sharp & Dohme Corp. is submitting the attached report detailing the activities, results, and conclusions from a comprehensive groundwater monitoring event conducted during the fourth quarter of 2018 at the Cherokee site located in Riverside.

We request EPA's and PADEP's review of the attached groundwater monitoring results. If you have any questions, or require additional information, please feel free to call me at (570) 271-2187.

Sincerely,

Heather Keller

Heather Keller

Attachments:
Fourth Quarter 2018 CMI Groundwater Monitoring and Progress Report

Heather Keller
Safety & Environmental Director
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April 26, 2019

Federal Express

Mr. Randy Farmerie, P.G.
Environmental Program Manager
PA DEP Northcentral Region
208 West Third St.- Suite 101
Williamsport, PA 17701

RE: Cherokee Pharmaceuticals, LLC Fourth Quarter 2018 Comprehensive Groundwater Monitoring Results

Dear Mr. Farmerie:

Cherokee Pharmaceuticals LLC, a Subsidiary of Merck Sharp & Dohme Corp. is submitting the attached report detailing the activities, results, and conclusions from a comprehensive groundwater monitoring event conducted during the fourth quarter of 2018 at the Cherokee site located in Riverside.

We request EPA's and PADEP's review of the attached groundwater monitoring results. If you have any questions, or require additional information, please feel free to call me at (570) 271-2187.

Sincerely,

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Attachments:
Fourth Quarter 2018 CMI Groundwater Monitoring and Progress Report

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April 26, 2019

Federal Express

Ms. Jessica Ritenour, P.G.
Environmental Group Manager
PA DEP Northcentral Region
208 West Third St.- Suite 101
Williamsport, PA 17701

RE: Cherokee Pharmaceuticals, LLC Fourth Quarter 2018 Comprehensive Groundwater Monitoring Results

Dear Ms. Ritenour:

Cherokee Pharmaceuticals LLC, a Subsidiary of Merck Sharp & Dohme Corp. is submitting the attached report detailing the activities, results, and conclusions from a comprehensive groundwater monitoring event conducted during the fourth quarter of 2018 at the Cherokee site located in Riverside.

We request EPA's and PADEP's review of the attached groundwater monitoring results. If you have any questions, or require additional information, please feel free to call me at (570) 271-2187.

Sincerely,

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Attachments:
Fourth Quarter 2018 CMI Groundwater Monitoring and Progress Report

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April 26, 2019

Federal Express

Mr. Eric Roof
Manager, Compliance & Enforcement
Susquehanna River Basin Commission
4423 North Front Street
Harrisburg, PA 17110

RE: Cherokee Pharmaceuticals, LLC Fourth Quarter 2018 Comprehensive Groundwater Monitoring Results

Dear Mr. Roof:

Cherokee Pharmaceuticals LLC, a Subsidiary of Merck Sharp & Dohme Corp. is submitting the attached report detailing the activities, results, and conclusions from a comprehensive groundwater monitoring event conducted during the fourth quarter of 2018 at the Cherokee site located in Riverside.

We request EPA's and PADEP's review of the attached groundwater monitoring results. If you have any questions, or require additional information, please feel free to call me at (570) 271-2187.

Sincerely,

Heather Keller

Heather Keller

Attachments:
Fourth Quarter 2018 CMI Groundwater Monitoring and Progress Report

Cherokee Pharmaceuticals, LLC

A Subsidiary of Merck Sharp & Dohme Corp.

Riverside, Pennsylvania

Fourth Quarter 2018 CMI Groundwater Monitoring and Progress Report

April 26, 2019

www.hatch.com

HATCH

Cherokee Pharmaceuticals, LLC

A Subsidiary of Merck Sharp & Dohme Corp.
Riverside, Pennsylvania

Fourth Quarter 2018
CMI Groundwater Monitoring
and Progress Report

April 26, 2019

Prepared by: Jason M. Fritz and Robert B. Warren, Jr.

Approved by: Douglas Dusbiber, P.G.

Project No.: H-356618

HATCH

1315 West College Avenue, Suite 100, State College, PA 16801

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/L	micrograms per liter
°C	degrees Celsius
%	percent
1,2-DCA	1,2-Dichloroethane
ACL	Alternate Concentration Limit
amsl	above mean sea level
CD	Compact Disc
cis-1,2-DCE	cis-1,2-Dichloroethene
CMI	Corrective Measures Implementation
CO&A	Consent Order and Agreement
COPC	Chemical of Potential Concern
DNAPL	Dense Non-Aqueous Phase Liquid
ELLI	Eurofins Lancaster Laboratories, Inc.
EPA	United States Environmental Protection Agency
ft	feet
ft amsl	feet above mean sea level
ft bgs	feet below ground surface
gpm	gallons per minute
IDW	Investigation-Derived Waste
LCS	Laboratory Control Sample
m	meters
MCL	EPA Maximum Contaminant Level
MSC	Medium Specific Concentration
MS/MSD	Matrix Spike / Matrix Spike Duplicate
ND	Not Detected
NEC	Net Exceedance Concentration
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
PADEP	Pennsylvania Department of Environmental Protection
PCE	Tetrachloroethene
PDB	Passive Diffusion Bag
QA/QC	Quality Assurance / Quality Control
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RPD	Relative Percent Difference
SDG	Sample Delivery Group
SHS MSC	Pennsylvania Act 2 Statewide Health Standard Medium Specific Concentration
SRA	Solvent Recovery Area
SWMU	Solid Waste Management Unit
TCE	Trichloroethene
TTHMs	Total Trihalomethanes
UST	Underground Storage Tank
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

This Corrective Measures Implementation (CMI) Groundwater Monitoring and Progress Report evaluates remedy performance and the need for continued remediation at the Cherokee Pharmaceuticals facility in Riverside, Pennsylvania. The groundwater monitoring portion of the report summarizes methods and results of the site-wide CMI groundwater monitoring event conducted from September 27, 2018, through November 1, 2018 (Fourth Quarter 2018 CMI groundwater monitoring event), while the progress report summarizes CMI activities performed and recommendations developed during the five-quarter reporting period which spans the timeframe from October 1, 2017 to December 31, 2018.

Groundwater samples were collected at 48 monitoring locations for volatile organic compound (VOC) analysis and water levels were measured to demonstrate the influence of site recovery wells. The comparison of the 2018 groundwater analytical data with historical sampling results demonstrates that the extent of groundwater contamination and the general disposition of VOC concentrations within the site have remained similar between successive CMI sampling events. These results indicate that, despite some constituent concentration fluctuations in 2018, the contaminant plume in the alluvial and bedrock aquifers is stable with respect to downgradient receptors; engineering controls and hydrogeologic constraints on groundwater flow pathways are preventing exposure to groundwater contaminants at levels above drinking water standards or that might pose unacceptable risk. Therefore, there is no indication of a change of potential risk associated with the contaminant plume in the alluvial and bedrock aquifers. Furthermore, following a trend described in previous CMI groundwater monitoring reports, the concentrations of total VOCs and individual VOC constituents were broadly lower in 2018 relative to long-term historical average VOC concentrations. These data provide evidence that there has been a long-term, broadly-based reduction of VOC constituent concentrations in most areas of the site.

Results of the site-wide water level monitoring conducted on September 27, 2018, showed that recovery well capture zones encompassed the former Solvent Recovery Area (SRA), Solid Waste Management Unit 1 (SWMU 1), and SWMU 2 source areas. This supports the conclusion that the recovery well system retains the capacity to hydraulically control the residual source areas.

Notable results from the 2018 monitoring event included (1) a suspect detection of the laboratory contaminant acetone (4.6 J µg/L) in the October 2, 2018 Southside Firehouse well sample (the result of a later re-sampling did not indicate the presence of acetone); (2) a slight increase in the TCE and chloroform concentrations at monitoring well MW-13D located to the east of the plant (the reported TCE concentration [22 µg/L] remains significantly lower than pre-2012 historical result and the chloroform concentration remains below the groundwater standard); (3) the continuation of the decrease in total VOC concentrations at monitoring well MW-32X in the deep bedrock aquifer following the increase observed in 2015; (4) the variability of VOC concentrations in samples from monitoring locations in the former SRA, including a significant increase in the MW-13S total VOC concentration; (5) variability in the chlorobenzene concentrations at multiple monitoring wells (e.g., MW-07S, MW-09D, MW-16D, MW-19S, MW-19D); and (6) the condition noted in 2017 where all of the VOC concentrations detected in the MW-02X sample were equal to, or below, their respective groundwater standards continued with the 2018 results as all VOCs detected were below the applicable standards).

SECTION 1
INTRODUCTION

1.1 OVERVIEW

This CMI Groundwater Monitoring and Progress Report evaluates remedy performance and the need for continued remediation at the Cherokee Pharmaceuticals facility in Riverside, Pennsylvania. The groundwater monitoring portion of the report summarizes methods and results of the site-wide CMI groundwater monitoring event conducted from September 27, 2018, through November 1, 2018 (Fourth Quarter 2018 CMI groundwater monitoring event). The work was comprised of groundwater sample collection at 48 monitoring locations for VOC analysis and water level monitoring to demonstrate the influence of site recovery wells. Site-wide CMI groundwater monitoring is performed once every five calendar quarters. The progress report portion summarizes CMI activities performed and recommendations developed during the preceding five-quarter reporting period.

The groundwater monitoring event was conducted in accordance with the CMI groundwater monitoring program field sampling plan (Appendix A, revised in 2016). The work occurred during a relatively wet period during the fall. There were no weather-related access issues related to the groundwater sample collection.

Monitoring and recovery wells historically sampled under the former Consent Order and Agreement (CO&A) with the PADEP are included in the five-quarter site-wide CMI groundwater monitoring schedule, where applicable. These include the East End sentinel wells MW-23D through MW-27D and site recovery wells. As during the previous four monitoring events, the Danville Area School District was not using the Riverside Elementary School for classes during the 2018-2019 school year. Consequently, the water system is not currently being utilized and sampling was not required during the 2018 monitoring event.

The CMI groundwater monitoring program was updated in 2015 to incorporate the modifications proposed in the CMI Five-Year Re-Evaluation Report (Chester Engineers, 2014b) and approved by EPA and PADEP (EPA, 2014), including the following: (1) removal of 11 monitoring wells, (2) removal of three analytical parameters, and (3) elimination of several isoconcentration contour maps from the five-quarter reports. The agencies' approval included a condition that if Cherokee proposes to shut down the recovery wells, Cherokee must resample monitoring wells MW-03S, MW-08M, MW-14M, MW-15D, MW-17M, and MW-17D as part of the site-wide sampling program to evaluate groundwater plume migration under static conditions (i.e., a requirement of the Statement of Basis).

1.2 OBJECTIVES

The objectives of the Fourth Quarter 2018 groundwater monitoring event included the following:

1. Identify and evaluate changes in the contaminant plume to assess its stability with respect to downgradient receptors and to ensure that there is no impact to downgradient receptors;

2. Monitor the performance of pumping to control groundwater migration from the residual source areas associated with the former East End Underground Storage Tank (UST) Farms (SWMUs 1 and 2) and the former SRA;
3. Compare the spatial distribution of detected constituents in the alluvial and bedrock aquifers with historical data; and
4. Evaluate the adequacy of the performance monitoring network.

The objective of the progress report portion of the CMI Groundwater Monitoring and Progress Report is to summarize the following information for the monitoring/reporting period:

1. CMI activities completed;
2. Changes made to the remedy;
3. Recommendations for remedy modifications; and
4. Projected work for the next reporting period.

1.3 ORGANIZATION OF REPORT

The report is organized into eight sections, including the preceding Executive Summary and this introduction, and six appendices. The selection of sampling locations and methods of groundwater sampling and analysis are described in Section 2. The analytical results and interpretation of the results are presented in Section 3. Water level monitoring results are provided in Section 4. Section 5 summarizes the conclusions drawn from the data and recommendations. Section 6 provides the CMI Progress Report and Section 7 lists references.

The appendices for the report are provided as electronic files on compact disc (CD). The CMI groundwater monitoring program field sampling plan is contained in Appendix A. Copies of field data sheets from the Fourth Quarter 2018 monitoring event are included in Appendix B. Appendix C summarizes laboratory analytical data from the 2003, 2005, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2015, 2016, 2017, and 2018 monitoring events. Appendix D contains copies of the laboratory analytical data packages from the Fourth Quarter 2018 monitoring event. Appendix E summarizes historical laboratory analytical data from 1991 to 2018. Quarterly well water level elevation data from 2017 and 2018 are included in Appendix F.

SECTION 2
METHODS

2.1 GENERAL

2.1.1 Groundwater Quality Monitoring Locations

The Fourth Quarter 2018 groundwater monitoring locations include wells screened in the alluvium, shallow bedrock, intermediate-depth bedrock, and deep bedrock. The alluvium overlies the bedrock and has a saturated thickness varying from 0 to about 20 feet (ft). The shallow bedrock groundwater monitoring zone is defined to extend from the base of the alluvium to a depth of approximately 150 ft below ground surface (bgs). The intermediate-depth zone extends from approximately 200 ft bgs to about 300 ft bgs. The deep bedrock zone extends from below 300 ft to about 900 ft bgs.

The CMI groundwater monitoring program was modified subsequent to the Fourth Quarter 2013 monitoring event with approval of EPA and PADEP (EPA, 2014). Modifications included the following: (1) removal of 11 monitoring wells [MW-03S, MW-08M, MW-10S, MW-10D, MW-14M, MW-15D, MW-17D, MW-17M, MW-20D, SW-K01, SW-N01], (2) removal of three analytical parameters [methanol, ethanol, and trans-1,2-dichloroethene] and (3) elimination of several isoconcentration contour maps from the five-quarter report. The agencies' approval included a condition that if Cherokee proposes to shut down the recovery wells, Cherokee must resample monitoring wells MW-03S, MW-08M, MW-14M, MW-15D, MW-17M, and MW-17D as part of the site-wide sampling program to evaluate groundwater plume migration under static conditions (i.e., a requirement of the Statement of Basis). The Fourth Quarter 2018 CMI groundwater monitoring event included the following monitoring locations:

- Eighteen locations in the alluvial aquifer (1 former vertical recovery well [RW-1], 1 horizontal recovery well [HSR-1], 4 performance monitoring wells in the former SRA [SR-series], 4 "source area" wells [SW-series], and 8 monitoring wells [MW-series]);
- Twenty-one locations in the shallow bedrock monitoring zone (5 recovery wells, 2 off-site wells, and 14 monitoring wells);
- Five monitoring wells in the intermediate-depth bedrock zone; and
- Four wells in the deep bedrock monitoring zone. MW-03XX provides down-dip monitoring of the same zone monitored by MW-03X, while MW-02X and MW-32X monitor this zone to the east and west at approximately the same depth as MW-03X.

These monitoring locations include 11 of the 14 wells previously sampled as part of the CO&A monitoring program (East End sentinel wells MW-23D through MW-27D and recovery wells RW-1, RW-1D, RW-2, RW-4, RW-9, and RW-OBS-6). The former [redacted] and [redacted] wells, which were historically sampled as part of the CO&A monitoring, have been abandoned with the approval of EPA and PADEP. The monitoring locations are listed in Table 1 and shown in Figure 1. The Danville Area School District was not using the Riverside Elementary School during the 2018-2019 school year and the well was unavailable for sampling during the 2018 monitoring event.

2.1.2 Analytical Parameters

Fourth Quarter 2018 groundwater samples were collected for analysis of VOCs. All groundwater samples, with the exception of the Southside Firehouse and Municipal Garage and associated Quality Assurance/Quality Control (QA/QC) samples were analyzed by Eurofins Lancaster Laboratories, Inc. (ELLI), for the VOCs listed in Table 2, in accordance with EPA SW-846 methods (i.e., SW-846 Method 8260B for VOCs). This list of Chemicals of Potential Concern (COPCs) was based on data collected during the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) and includes ten constituents requested by the PADEP in the October 28, 2002, letter (PADEP, 2002). EPA and PADEP approved the removal of three analytes (trans-1,2-dichloroethene, methanol, and ethanol) from the monitoring program subsequent to the Fourth Quarter 2013 monitoring event.

Samples from the Southside Firehouse and Municipal Garage wells, as well as associated QA/QC samples were analyzed by ELLI using EPA Method 524.2 for the Drinking Water VOC list plus the following site-specific constituents: acetone, ethyl ether, tetrahydrofuran, and methyl ethyl ketone. In addition, ethyl acetate and cyclohexane were analyzed using EPA SW-846 Method 8260B. Methanol and ethanol were removed as analytes with EPA and PADEP approval subsequent to the Fourth Quarter 2013 monitoring event. Table 3 summarizes sample containers, holding times, and preservation requirements for each analytical method.

2.2 FOURTH QUARTER 2018 WELL PURGING AND SAMPLING METHODS

Monitoring well purging and sampling were conducted in accordance with the CMI groundwater monitoring program field sampling plan (Appendix A). The field sampling plan was updated in 2015 to reflect a reduction in the monitoring locations and analytes and in March 2016 to incorporate flexibility in achieving water level stabilization during low-flow purging. Variations from sampling protocols are noted below or documented in Table 1 or in the field sheets in Appendix B. Prior to purging and sampling, the water level was recorded and the well was inspected to determine the need for equipment installation and/or repairs.

Low-flow sampling, using the EPA low-flow method as described by Puls and Barcelona (April 1996), was specified at many sampling locations. As in previous events, alternatives to the low-flow sampling procedures were employed at operating recovery wells, East End sentinel wells (MW-23D through MW-27D), Municipal Garage well, Southside Firehouse Well, deep bedrock wells (MW-02X, MW-03X, MW-32X, and MW-03XX), wells with dedicated packers, and low-yielding wells.

Low-flow groundwater sampling methods are considered to be a reliable means to obtain samples that are representative of the aquifer groundwater quality. The use of the low-flow sampling method is expected to provide for the collection of groundwater analytical data at least as reliable as those collected during the RFI, which had been collected after purging three well volumes, or in the case of low yield wells, after the purge and recovery of one well volume.

The following subsections describe the methods of purging and sampling at several types of monitoring locations. Additional detailed information regarding the sampling methods utilized at each monitoring location is listed in Table 1.

2.2.1 CMI Groundwater Performance Monitoring Wells

Many of the CMI groundwater performance monitoring wells are equipped with dedicated purge/sample bladder pumps constructed of Teflon and stainless steel, which are generally well suited to low-flow groundwater sampling. Otherwise, wells were sampled with a peristaltic pump and clean (i.e., new) polyethylene tubing using procedures specified in the CMI groundwater monitoring program field sampling plan (Appendix A).

Water level drawdown exceeded the target range (0.1 m) stated in the CMI groundwater field sampling plan at multiple locations due to well performance characteristics and sampling equipment limitations. At locations where water level stabilization could be achieved, the use of low-flow sampling procedures was considered superior for the collection of representative samples to the use of alternative sampling methods. EPA guidance (Puls and Barcelona, April 1996) recognizes that minimal drawdown may be difficult to achieve due to geologic heterogeneities within the screened interval and may require adjustment based on site-specific conditions and personal experience. The CMI groundwater field sampling plan was updated in March 2016 to incorporate flexibility in achieving water level stabilization during low-flow purging (see Appendix A).

Most of the intermediate-depth wells contain dedicated inflatable packers, which isolate the screened interval and reduce the purge volume required for the three well-volume purge and sample method. Packer inflation was not necessary if water level stabilization could be obtained during low-flow purging. For one low-yielding, intermediate-depth well where water-level stabilization does not occur (MW-25M), the packer was inflated and the well was purged as discussed in the CMI groundwater field-sampling plan. After sufficient volume was removed, the groundwater sample was extracted from the packed interval using the dedicated bladder pump.

2.2.1.1 Modified Low-Flow Methods

Modified low-flow methods were used for five wells having low yields and/or low water levels (MW-12D, MW-12M, MW-12S, MW-13S, and SR-08). Standard low-flow sampling has been shown to be impracticable at all of these wells because the pumping water level continues to decrease while pumping at very low flow rates (e.g., approximately 100 ml/minute). The alternative methods used at these wells are described below.

Currently, there is no established regulatory protocol for sampling low yield wells. Where possible, the methods used to purge these wells followed the PADEP Groundwater Monitoring Guidance Manual (PADEP, 2001) suggestion that low-yield wells be purged in a manner so that the water level does not fall below the well screen. The following methods were used for these wells:

1. Monitoring wells MW-12D and MW-12M were purged and sampled with existing bladder pump systems, using a modified low-flow method for wells where more than half the well water volume is located above the well screen (Alternate Method 2 in Appendix A). Monitoring well MW-12D was purged until the water level reached the top of the well screen. At this point, more than one-half well volume of water had been removed from the well. After recovery, an additional volume of water equal to that contained in the screened interval was removed,

resulting in the removal of a full well volume prior to sampling. The required groundwater sample was collected from the midpoint of the screened interval after the well had fully recovered. MW-12M was purged to remove a minimum of one well volume over the course of two separate purging events (see explanation in Table 1). After one well volume had been purged, and the well had recovered, the sample pump located inside the screened interval was used to collect the sample.

2. Monitoring wells SR-08, MW-12S, and MW-13S were sampled using a modified low-flow method for wells having less than half of the well water volume above the well screen (Alternate Method 1 in Appendix A). The water level in these wells was determined to be within their screened intervals. A submersible electric Whale pump was used to purge one well volume from SR-08. MW-12S was purged using the existing bladder pump over two separate events until one well volume was purged. MW-13S was purged of more than one well volume using the existing bladder pump during one event. The wells were sampled after sufficient recovery had occurred.

2.2.1.2 Passive Diffusion Bags

Passive diffusion bags (PDBs) were used to sample MW-02X, MW-03X, MW-32X, and MW-03XX for VOCs, as specified in the CMI groundwater field sampling plan. The PDB sampling technique involves suspending a set of low-density polyethylene bags filled with laboratory-supplied deionized water at the selected sampling depth. The bags were suspended using stainless steel wire and are allowed to remain for two weeks. During this time, the water within the PDB reaches chemical equilibrium with the surrounding well water via diffusion through the PDB wall.

The PDB method was used because of the impracticality of using purging techniques in the deep wells. In addition, water level responses observed in MW-02X and MW-03X while purging MW-03XX during the deep bedrock hydrogeologic investigation provided evidence that additional purging of MW-03XX could induce or accelerate downward migration of contamination from the vicinity of MW-03X (N.A. Water Systems, 2004).

On September 26, 2018, PDBs were set in MW-02X, MW-03X, MW-32X, and MW-03XX at depths of approximately 493, 517, 395, and 813 ft bgs, respectively. The installation depth in MW-02X was within the interval that contained the highest VOC concentrations, based on January 2004 packer testing results (N.A. Water Systems, 2004). The installation depth in MW-03XX was at the midpoint (813 ft bgs) of the open interval (739 to 888 ft bgs), because VOC concentrations and yield were relatively evenly distributed. The PDB setting depth in MW-03X was approximately six inches from the bottom of the well (at approximately 517 ft bgs), which was slightly higher than the pump intake setting during the 2003 and 2005 monitoring events. The PDB setting depth in MW-32X was the same as that used in 2015 through 2017, but approximately 13 feet higher (395 ft bgs) than the depth used in previous events (408 ft bgs, the midpoint of the highest yielding 25-foot zone [395-420 ft bgs] identified in the January 2004 packer testing results [N.A. Water Systems, 2004]). In 2015, an obstruction was encountered at approximately 395 ft bgs depth, and at which the group of three PDBs (necessary to collect both the primary sample and field duplicate sample) could not be maneuvered past. The obstruction was subsequently removed, but the 2015 PDB setting depth has been maintained because the 2015 total VOC concentration increased relative to the 2013 monitoring event.

Two weeks later, on October 10, 2018, the PDBs were retrieved from MW-02X, MW-03X, MW-32X, and MW-03XX. Samples were collected from the PDBs by cutting open the bags and transferring the contents to sample containers. Additionally, after retrieval of the PDB from MW-03X, an interface probe was used to confirm that no dense non-aqueous phase liquid (DNAPL) had accumulated at the bottom of the well. The analytical results are discussed in Sections 3 and 4.

2.2.1.3 East End Sentinel Wells

Monitoring wells MW-23D through MW-27D, the East End sentinel wells historically sampled under the former CO&A with the PADEP, were purged and sampled using the dedicated well-wizard bladder pump system. Purging was conducted using "three-well volume" methods in which certain wells were purged dry and the remainder of the purge volume was removed after sufficient recovery, as was historically performed under the CO&A.

2.2.2 Recovery Wells

Groundwater samples were collected from site recovery well sample ports on October 3 (recovery wells RW-1D, RW-2, RW-4, RW-9, and RW-OBS-6), and October 9, 2018 (horizontal recovery well HSR-1). Sufficient water was purged through each sample spigot to ensure that the discharge line was flushed of potentially stagnant water. Former recovery well RW-1 has not been in operation since November 2004 due to partial collapse of the screened interval. RW-1 was sampled on October 3, 2018, using low-flow sampling techniques.

Recovery well operational data from September 26, 2017, through December 25, 2018, are provided below:

Recovery Well	Total Volume Pumped (Gallons)[1]	Total Operating Time (Hours)[1]	Average Rate (gpm)[2]
RW-2	5,391,708	10,842.4	8.3
RW-4	2,404,246	10,329.2	3.9
RW-9	1,517,909	10,839.9	2.3
RW-1D*	306,867	1,936.6	2.6
RW-OBS-6	12,378,196	10,876.2	19.0

1 Gallons and hours from September 26, 2017, to December 25, 2018, are estimated based on periodic meter readings. Asterisk (*) indicates that the total flow may be underestimated due to periods when the pump may have run at a low flow rate below the flow meter range.

2 Average pumping rate while well is in operation (i.e., total volume divided by total operating time).

Recovery Well	Total Volume Pumped (Gallons)[1]	Total Operating Time (Hours)[1]	Average Rate (gpm)[2]
HSR-1*	2,284,441	9,974.6	3.8
TOTAL	**24,283,367**	-	-

1 Gallons and hours from September 26, 2017, to December 25, 2018, are estimated based on periodic meter readings. Asterisk (*) indicates that the total flow may be underestimated due to periods when the pump may have run at a low flow rate below the flow meter range.

2 Average pumping rate while well is in operation (i.e., total volume divided by total operating time).

As shown in the preceding table, approximately 24.3 million gallons of groundwater were recovered during the 15 month (455 day) monitoring period. The recovered water was treated at the site's wastewater treatment plant and discharged into the Susquehanna River through the National Pollutant Discharge Elimination System (NPDES) outfall. The volume of groundwater extracted is not being used as a direct indicator that the remedy is performing toward its stated objectives; groundwater level monitoring is the selected performance measure for the groundwater extraction remedy. The total volume of water pumped during this monitoring period is slightly higher than that reported for the previous period, as all recovery wells were operating more consistently.

Routine maintenance, consisting of pump cleaning and meter calibration was periodically performed at each of the wells. More extensive maintenance, such as pump replacement or well rehabilitation, was conducted as needed based on well performance. The following describes performance issues encountered that required investigation and/or repair during the 2017-2018 monitoring period.

- On November 15, 2017, an attempt was made to pull the RW-2 pump and motor for cleaning, however an obstruction within the borehole prevented removal of the pump and discharge piping. Since the scheduled maintenance was preventative in nature, the pump was reconnected and pumping resumed with continued monitoring of performance. On July 19, 2018, a pump hoist was used to attempt pulling the pump, however the pump became lodged at approximately 66 feet below top of casing (BTOC) and the discharge pipe became separated from the pump. A new pump, motor, and motor lead were installed at 60 feet BTOC (approximately 19 feet above the previous pump setting depth of 79 feet BTOC) and normal operation was resumed. As discussed in the Third Quarter 2017 CMI Groundwater Monitoring and Progress Report (Hatch Chester, 2018), it was discovered that RW-2 had experienced some collapse from its previous depth of 96 feet to 85 feet below top of casing. From examination of the collapsed material, it was determined that the well casing may be compromised, allowing overburden material to enter the wellbore.

- HSR-1 was out of service for the weekly measurements made on February 6, February 13, and February 20, 2018, due to pump/motor failure. On February 22, 2018, the pump and motor were replaced and normal operation was resumed. Cleaning of the discharge piping between the pump and the cabinet was also conducted at this time.

- On July 19, 2018, it was discovered that RW-4 was not operating and that the thermal overload had been tripped. Review of recorded data from the datalogger revealed that the overload had tripped on July 14, 2018. The overload was reset and normal pumping was resumed until the overload tripped again on August 5. It was determined that the motor was running at higher amperage than normal. On August 23, 2018, the pump and motor were replaced and normal operation was resumed.
- Merck site personnel determined on December 11, 2018, that the RW-1D pump was running however no flow was being produced. Hatch determined on December 17 that the RW-1D pump was not shutting off when the water level reached the lower level probe. On December 19, the control relay was replaced, however the issue remained. On January 25, 2019, the level probes and wiring were replaced and normal operation was resumed.
- A chronological summary of recovery well repair work performed during the current monitoring period is shown below:

Date	Well	Well and Repair Type
October 2017	RW-1D, RW-2, RW-4, RW-9, RW-OBS-6, HSR-1	Flow indicators and totalizers calibrated.
	RW-4	Disinfection using 5.25% sodium hypochlorite bleach.
November 2017	RW-4	Clean pump and motor.
February 2018	HSR-1	Replace pump and motor; clean discharge piping between pump and cabinet.
April 2018	RW-1D, RW-2, RW-4, RW-9, RW-OBS-6, HSR-1	Flow indicators and totalizers calibrated.
	HSR-1	Replace flow meter.
July 2018	RW-2	Replace pump, motor, and motor lead; raise pump, transducer, and lower level probe setting depths.
	RW-1D	Clean pump and motor; replace pitless adaptor.
August 2018	RW-4	Replace pump and motor.
	RW-9	Clean pump and motor.
November 2018	RW-1D, RW-2, RW-4, RW-9, RW-OBS-6, HSR-1	Flow indicators and totalizers calibrated.
December 2018	RW-4	Disinfection using 5.25% sodium hypochlorite bleach.
	RW-1D	Replace control relay.

2.2.3 Municipal Garage and Southside Firehouse

The Municipal Garage well (sample identified as MUN GAR) and the Southside Firehouse well (sample identified as SSFH) were sampled on October 2, 2018. The SSFH well was resampled on November 1, 2018, due to a low detection of acetone in the October 2 sample, as discussed in Section 3. Both wells were sampled at designated indoor faucet locations. The Municipal Garage well is not used by employees as a source of potable water. The Southside Firehouse well is used as a potable water source.

2.3 WATER LEVEL MONITORING LOCATIONS

Water level measurements were made at wells specified in the CMI groundwater monitoring program field sampling plan (Appendix A) on September 27, 2018 (Table 15), as well as at each sampling location prior to purging. Additionally, an interface probe was used to confirm that there was no accumulation of DNAPL at the bottom of monitoring well MW-03X on October 10, 2018.

2.4 FIELD PARAMETERS

Field parameters were measured at each monitoring location sampled using low-flow sampling methods and some locations where alternate methods were used during the Fourth Quarter 2018 monitoring event. For low-flow sampling methods, the following field parameters were measured with a YSI multi-parameter meter and flow-through cell: pH, specific conductance, oxidation-reduction potential (ORP), temperature, and dissolved oxygen. Measurements were recorded on field data sheets approximately every five minutes while purging. The field data sheets are reproduced in Appendix B. Purging continued until pH, temperature, specific conductance, ORP, and dissolved oxygen had stabilized within the target ranges for at least three consecutive readings prior to sampling:

- ±0.1 units for pH;
- ±3% for specific conductance;
- ±10 mV for ORP;
- ±10% for temperature;
- ±10% for dissolved oxygen.

2.5 DECONTAMINATION AND DISPOSAL

Equipment was decontaminated in accordance with the CMI groundwater monitoring program field sampling plan (Appendix A) as follows:

- Dedicated sampling equipment, disposable sampling equipment (e.g., tubing), and peristaltic pumps were not subject to decontamination.
- A dedicated submersible pump (only used at SR-08) was washed and flushed with a laboratory-grade detergent solution (Liquinox and water) and then rinsed with distilled water. Submersible pump power supply cables were also washed with the decontamination solution and rinsed.
- Portable field meters and beakers were rinsed with distilled water after each use.

- Investigation-derived waste (IDW) was disposed in accordance with the CMI groundwater monitoring program field sampling plan (Appendix A) as follows:
  - Water and detergent used for decontamination were discharged to the on-site wastewater treatment plant.
  - Groundwater purged from monitoring locations was collected and discharged to the on-site wastewater treatment plant, except that from East End sentinel wells MW-23D through MW-27D. Purge water from these locations was allowed to discharge to the ground, because the water is considered uncontaminated.
  - Disposable solids, such as paper towels, plastic sheeting, pump tubing, and personal protective equipment, were containerized for proper off-site disposal.

2.6 SAMPLE HANDLING AND SHIPMENT

Immediately after sampling, the VOC vials were placed on ice in a cooler to maintain the temperature at approximately 4 degrees Celsius (°C). The samples were stored overnight on site in a dedicated sample refrigerator until they were shipped to the laboratory via courier.

2.7 FIELD METER CALIBRATION

Field meters were calibrated before sampling at the start of every field day and calibration checks were made at least once each day. Calibration data were recorded on field data sheets.

2.8 QUALITY ASSURANCE AND QUALITY CONTROL SAMPLES

Quality assurance and quality control methods included the collection and/or preparation of field and laboratory QA/QC samples for the VOC analyses. The following field QA/QC samples were collected or supplied by the laboratory:

- Trip blank – One trip blank for VOC analysis was submitted for each sample shipment container. Trip blanks were prepared by the laboratory, accompanied the sample vials to the field, and remained with the samples until returned to the laboratory.
- Field/equipment blank – One field blank was collected for every 20 groundwater samples collected. The field/equipment blank for the PDB sampling methodology was prepared by collecting a sample from an unopened PDB that had been stored on-site during the two-week period that the PDBs were installed in the deep bedrock monitoring wells. The remaining field blanks were prepared by pouring laboratory-supplied analyte-free water into sample vials at a designated wellhead sampling location.
- Duplicate sample – For every 20 groundwater samples collected, one duplicate sample was collected. The primary and duplicate samples were collected in a manner that produced two homogeneous samples. The duplicate samples were submitted to the laboratory as "blind" samples.
- Matrix spike/matrix spike duplicate (MS/MSD) – For every 20 groundwater samples collected, one sample was collected in triplicate to be used for the laboratory MS/MSD analyses.

In addition to the schedule described above, one complete set of the QA/QC samples was collected for each of the following groups of wells, as per the CMI groundwater monitoring program field sampling plan (Appendix A): East End sentinel wells, and the Riverside water supply wells (i.e., Municipal Garage and Southside Firehouse). Additional laboratory QC samples required by the analytical methods include surrogate spikes, laboratory control samples, and method blanks.

2.9 DOCUMENTATION

Sampling information was recorded on Chain-of-Custody Forms and monitoring well sampling data sheets. Copies of this information are provided in Appendices B and D.

2.10 DATA ANALYSIS METHODS

Several methods were used to analyze data collected during the Fourth Quarter 2018 monitoring event. Groundwater VOC concentrations were compared statistically with historical data to determine how the Fourth Quarter 2018 data differed from the population of results obtained during the site corrective action program (as a clarification to the January 1990 historical data benchmark, the RFI groundwater sampling was initiated in December 1991 and represent the earliest data included for some monitoring locations; while the sampling of certain other locations was initiated more recently). Constituent concentrations from 2018 were also compared directly to concentrations from the previous CMI monitoring events (see summary table in Appendix C).

Two types of maps were prepared to illustrate the groundwater constituent distributions: (1) isoconcentration contour maps of the sums of VOC concentrations exceeding relevant groundwater standards in the alluvial and shallow bedrock zones; and (2) bar graph maps showing concentrations for all detected COPCs in the alluvial aquifer, and the shallow, intermediate, and deep intervals of the bedrock aquifer. EPA and PADEP have agreed that the isoconcentration contour maps for individual VOCs in the alluvial and shallow bedrock zones prepared for previous reports are no longer needed (EPA, 2014).

The VOC contouring methodology used to create the maps of the sums of VOC concentrations exceeding relevant groundwater standards was the same as that used for the reports of the 2006 through 2017 monitoring events. However, this methodology differs from that of the 2003 and 2005 groundwater monitoring reports, in which mapped "total VOC" isoconcentration contours represented the sum of individual VOC concentrations at each well. The values shown on the 2018 maps represent the sum of the VOC "net exceedance concentrations" (i.e., the total VOC NEC) for the detected constituents; the VOC NEC is calculated as the detected constituent concentration minus the relevant groundwater standard. Where the detected concentration is less than the relevant standard, a value of zero has been substituted for the negative value that would result from the subtraction. There are two advantages to displaying the data in this manner. The first advantage is that the map incorporates a measure of the significance of the detected VOC concentrations, because only the areas that exceed relevant groundwater standards are shaded. The second advantage is that the map contours are better constrained by "zero" values, especially in the southern and western portions of the site, where detected constituent concentrations are often below standards. The use of zero values at these locations imparts a conservative bias to the maps, making the estimated areas requiring remediation slightly larger than they otherwise would be.

Total NEC maps for the alluvial and shallow bedrock zones are included in this report for the previous CMI monitoring events (i.e., 2003, 2005, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2015, 2016, and 2017 groundwater monitoring data) to facilitate comparisons with the 2018 data and future monitoring data.

The groundwater standards used for the 2018 total NEC map calculations (shown in Table 4) were established from the following sources, in order of priority: (1) EPA Maximum Contaminant Levels (MCLs); (2) Pennsylvania Act 2 Statewide Health Standard Medium Specific Concentrations (SHS MSCs) under a very conservative residential exposure scenario; and (3) the health-based standard established for bromobenzene as an action level for the former monthly groundwater monitoring conducted east of the facility. Pennsylvania published revised Act 2 SHS MSCs on January 8, 2011, which resulted in changes (mostly increases) to the groundwater standards for seven of the original CMI monitoring program analytes. Additional changes were published on August 27, 2016 for three of these analytes. Changes are shown as follows:

Analyte	Previous Groundwater Standard (µg/L)	2011 Revised Groundwater Standard (µg/L)	2016 Revised Groundwater Standard (µg/L)
Acetone	3,700	33,000	38,000
Acetonitrile	170	130	No change
Ethanol*	4,900	8,400	No change
Ethyl ether	1,900	7,300	8,300
n-Hexane	550	1,500	No change
Methanol*	4,900	8,400	No change
Tetrahydrofuran**	5	25	26

* Ethanol GWS based on PA Act 2 SHS MSC for similar compound methanol. Ethanol and methanol dropped from analytical list as of 2015

** Tetrahydrofuran was formerly a "threshold of regulation" compound

The revisions to the Act 2 SHS MSCs are incorporated in the 2011 through 2018 total VOC NEC maps for the alluvial and shallow bedrock aquifers (Figures 2 and 3). The 2015 through 2018 NEC maps do not include calculations for three analytes (methanol, ethanol, and trans-1,2-dichloroethene) which were infrequently detected in previous events and were removed from the analytical program with EPA and PADEP approval (EPA, 2014).

Piezometric surface contour maps for the alluvial aquifer and the shallow, intermediate, and deep intervals of the bedrock aquifer were prepared from well water level measurements made on September 27, 2018. The method of kriging, a geostatistical technique, was used in the preparation of the concentration and piezometric surface contour maps. Surfer (Version 10, Golden Graphics, Inc.) was used to implement two-dimensional krig estimates and generate contour lines. The same software was used to develop estimation parameters used by the krig analysis by fitting model variograms to the field (experimental) data. Certain parameters, such as the anisotropy employed by the search algorithm, were adjusted to reflect knowledge of hydrogeologic conditions in the alluvial and bedrock aquifers and the locations of known source areas. In some cases, this knowledge also was used to make appropriate adjustments to the contours generated by Surfer.

SECTION 3
RESULTS OF VOLATILE ORGANIC COMPOUND ANALYSIS

This section summarizes the results of VOC analyses for the Fourth Quarter 2018 monitoring event, including the QA/QC data. Analytical results for the event are presented in Tables 4 and 5. Table 4 lists analytical results for the CMI groundwater performance monitoring locations including site monitoring wells, recovery wells, and East End sentinel wells and associated QA/QC samples (see Section 3.4). Table 5 lists analytical results for the Municipal Garage and Southside Firehouse well samples and associated QA/QC samples.

Fourth Quarter 2018 data were compared to recent and long-term historical data to evaluate changes in the configuration and extent of the contaminant plume (Section 3.1). Appendix C provides a summary of the analytical results for each well from the 13 monitoring events between 2003 and 2018 and Appendix E provides a summary of historical analytical results since the start of the RFI. The analytical results were also used to map the position and concentration of the contaminant plume (Sections 3.2 and 3.3). An objective of these analyses was to determine whether the data indicate potential changes in the level of risk to human and ecological receptors. In summary, the analytical results of the Fourth Quarter 2018 monitoring event indicate that, despite constituent concentration fluctuations at certain locations, the contaminant plume in the alluvial and bedrock aquifers continues to remain stable with respect to downgradient receptors; engineering controls and hydrogeologic constraints on groundwater flow pathways are preventing exposure to groundwater contaminants at levels above drinking water standards or that might pose unacceptable risk. Therefore, the site conceptual model remains valid with respect to the risk to downgradient receptors.

3.1 STATISTICAL COMPARISON OF FOURTH QUARTER 2018 VOC DATA WITH HISTORICAL DATA

Sections 3.1.1 to 3.1.4 provide comparisons of analytical results from Fourth Quarter 2018 samples with summary statistics derived from historical samples collected since 1990. These comparisons are based on actual detected constituent concentrations; the term "total VOC", where used, represents the sum of individual constituent concentrations at a specific sampling location, regardless of whether the concentrations exceed relevant groundwater standards. Historical average, maximum, and minimum concentrations were determined for each monitoring well and analyte, and the relative percent differences of the Fourth Quarter 2018 results were calculated with respect to these statistics. Results of the calculations for the alluvial aquifer are summarized in Tables 6 and 7; for the shallow bedrock aquifer in Tables 8 and 9; for the intermediate-depth bedrock aquifer in Tables 10 and 11; and for the deep bedrock aquifer in Tables 12 and 13. The tables list results for each analyte and sample location sampled in the Fourth Quarter 2018 sampling event. The first of the two tables provided for each monitoring zone lists the Fourth Quarter 2018 results and summary statistics for historical results. The second table lists relative percent differences (RPDs) of Fourth Quarter 2018 detections from the historical statistics based on the following formula:

RPD = 100% x (2018 result – historical statistic)/historical statistic.

Analytes that were not detected in 2018 do not have an entry in the tables of relative percent differences unless the limit of quantitation (LOQ) was less than an historical detection of that analyte at that location. If so, an "ND<Hist" entry is shown. In tables listing relative percentage difference from historical statistics, an entry of "Equal" indicates that the 2018 result was equal to the historical statistic for that analyte at that location. Yellow highlights indicate increases, and green highlights indicate decreases. Entries of "Equal" are not highlighted but, in some cases, can indicate the initial detection of a compound at a monitoring location.

It should be noted that the summary statistics were derived from the population of historical samples since January 1990 and includes all the RFI and CMI groundwater monitoring through 2018. This was done because the significant differences of sampling histories at various locations did not permit the definition of sample populations having a common time frame without the inclusion of the 2003 through 2017 CMI groundwater monitoring sample results (or alternatively the exclusion of significant numbers of samples) in the calculation of historical statistics. For example, prior to the fall 2003 groundwater monitoring event, many monitoring wells had not been sampled since 1999, whereas monitoring wells in the CO&A program were sampled multiple times between 1999 and 2003. As a result of the differing sampling histories, there are unavoidable differences in the sampling biases relative to time at different locations. It should also be noted that, starting in 2015, 11 wells and three analytes were removed from the monitoring program with EPA and PADEP approval (EPA, 2014). The historical summary statistics for the wells and analytes recently removed from the monitoring program are still included on the tables for historical context; the cells containing the 2018 result (e.g., on Table 6) and those that would have been previously populated with comparison data (e.g., on Table 7) are identified with an "NA" (not applicable) to indicate that the well was not sampled or the parameter was not analyzed.

The statistical comparisons indicate that the alluvium, shallow bedrock, intermediate-depth bedrock, and deep bedrock aquifer 2018 results are reduced relative to long-term historical statistics at most locations and for most analytes. This is to be expected of the comparisons with historical maximum concentrations, but it is also the case that the 2018 results remain broadly lower than historical averages. The same conclusion was drawn from the comparison with historical statistics made after the all of the site-wide sampling events performed from 1999 through 2017 (Merck & Co., Inc., 2000; Veolia Water Systems, 2004; N.A. Water Systems, 2005; N.A. Water Systems, 2007a; N.A. Water Systems, 2007b, Chester Engineers, 2009; Chester Engineers, 2010b; Chester Engineers, 2011; Chester Engineers, 2012; Chester Engineers, 2014a; Chester Engineers, 2015, Chester Engineers, 2016b, Hatch Chester, 2018). Because each annual comparison includes the data used to make the previous year's comparison, VOC concentrations must continue to decline in order to continue to make this conclusion over time.

Notable results from the 2018 monitoring event included (1) a slight increase in the TCE concentration at monitoring well MW-13D located to the east of the plant (the reported concentration [22 µg/L] is within the concentration range that was reported from 2012 to 2017 [7 µg/L to 31 µg/L] and remains significantly lower than historical pre-2012 CMI results [480 µg/L to 1,200 µg/L]); (2) the continued decrease in total VOC concentrations at monitoring well MW-32X in the deep bedrock aquifer following the increase observed in 2015; (3) the variability of VOC concentrations in certain samples from monitoring locations in the former SRA; (4) variability of chlorobenzene concentrations in MW-19S, MW-19D, MW-07S, and MW-

09D; and (5) continued decreases in the total VOC concentrations in samples from deep wells MW-02X and MW-03XX.

Several constituent concentrations detected in 2018 samples exceeded historical average concentrations. There were four increases relative to historical averages in samples from the alluvial aquifer monitoring locations, one of which was in the HSR-1 sample and one of which was in the sample from nearby monitoring well MW-24S within the former SRA. Observed variability of VOC concentrations in samples from wells in the former SRA is likely related to the effects of HSR-1 operation on groundwater flow paths. There were eleven constituent concentrations in samples from individual bedrock monitoring wells locations that exceeded historical average concentrations. Most of these results were insignificant in that they were similar to other recent data, represented very low detected concentrations, or were collected from recovery wells or monitoring well MW-03X. The only results that were unusual or significant were the following: (1) the detection of chlorobenzene in the monitoring well MW-19D sample (270 µg/L) exceeding the average concentration of approximately 239 µg/L and (2) the MW-12M detections of benzene (11 µg/L, the maximum detected at this location) and chlorobenzene (8 µg/L, which exceeds the average [5.23 µg/L] and increased from 2017 [3 µg/L]).

3.1.1 Statistical Comparisons of VOC Data from the Alluvial Aquifer

In approximately 97 percent of 134 comparisons to historical statistics for the alluvial aquifer (Tables 6 and 7), the 2018 results were lower than or equal to historical averages. This total includes those non-detected results that are shown as ND<Hist on Table 7 (i.e., a non-detected result for given analyte at a given location with an LOQ that was less than an historical detection of that analyte at that location), which represent approximately 46 percent of the comparisons. However, the total does not include non-detected constituents with an LOQ higher than (or equal to) a previous detection at a monitoring location (i.e., non-detected values shown on Table 6 that have blank entries on Table 7).

The 2018 sampling event occurred following a period of wet weather during both the preceding two weeks and the preceding month of September. Horizontal recovery well HSR-1 was in service during the monitoring event; the water levels in the former SRA were higher than those reported during the 2017 and 2016 monitoring events, but lower than during the 2015 event, when the HSR-1 pump was not operating (i.e., under static conditions). Constituent concentration variability in the former SRA with respect to recent previous results is interpreted to reflect the effects of sustained HSR-1 pumping on the complex nature of the contaminant distribution and groundwater flow within the former SRA. Outside the former SRA and the influence of recovery well HSR-1, water levels measured in alluvial aquifer monitoring wells on September 27, 2018 were higher than, or similar to, those measured in August 2017 (see Section 4). The effects of seasonal variation are not broadly evident in the monitoring data, but differences in recharge conditions may have locally affected constituent concentration variability.

Table 7 shows that there were four increases relative to historical averages in the alluvial aquifer from three well locations, two of which were likely related to the operation of horizontal recovery well HSR-1 in the former SRA. As in 2017, one of the increases was in the sample from HSR-1 (chlorobenzene, 2,300 µg/L, slightly lower than the 2017 result [2,400 µg/L]). The remaining three increases were at SRA monitoring well MW-24S (cis-1,2-dichloroethene, [2 µg/L]), RW-01 (chloroform, [32 µg/L]), and MW-07S (chlorobenzene [170 µg/L]). These reported increases do not indicate a change in risk to potential receptors. The increases in the HSR-1 and MW-24S samples most likely reflect variability associated with the contaminant distribution and groundwater flow pathways within the former SRA. The HSR-1 chlorobenzene concentration (2,300 µg/L) is similar to that reported in 2017 (2,400 µg/L) and 2016 (2,500 µg/L). The MW-24S cis-1,2-dichloroethene result (2 µg/L) is low enough to be similar to all previous CMI results (both detects and non-detects) and is well below the groundwater standard (70 µg/L). The RW-01 chloroform concentration (32 µg/L) is the highest detected at this location during the CMI but is within the range of historical detections and is below the groundwater standard (80 µg/L). The MW-07S chlorobenzene result (170 µg/L) is the highest concentration reported since 2003 (200 µg/L), but is similar to recent results (e.g., 140 µg/L in 2015) and the MW-07S total VOC (and total VOC NEC) concentrations have declined significantly during the CMI.

The concentrations of total and individual VOC concentrations in wells in the vicinity of horizontal well HSR-1 varied, but were mostly lower than or similar to those reported for the Third Quarter 2017 monitoring event. The most notable exception was that the 2018 total VOC concentration in the sample from MW-13S (6,170 µg/L) was significantly higher than that reported in 2017 (876 µg/L), mostly due to a significantly higher tetrahydrofuran concentration. Other notable results included:

- The 2018 total VOC concentration in the sample from SR-03 (3,820 µg/L) was lower than that reported in 2017 (5,013 µg/L) and much lower than that reported in 2016 (26,414 µg/L), mostly due to a decrease in benzene concentration (1,000 µg/L in 2018, compared to 2,600 µg/L in 2017 and 24,000 µg/L in 2016).

- As was the case in 2015, there were no VOCs reliably detected in the 2018 sample from SR-04; the 2017 total VOC concentration was 1,757.9 µg/L and the 2016 total VOC concentration was 452 µg/L, both comprised primarily of ethyl ether.

- The 2018 total VOC concentration in the sample from SR-08 (98.7 µg/L) is significantly lower than that reported in 2017 (855.7) and 2016 (2,187 µg/L), mostly due to decreases in benzene and toluene concentrations.

The observed constituent concentration variability at individual wells within the HSR-1 zone of influence in the former SRA is not significant with respect to risk to potential receptors for the following reasons: (1) high VOC concentrations have been historically detected in monitoring wells in the former SRA and (2) the groundwater in the former SRA is captured by recovery well HSR-1. Furthermore, concentration fluctuations at these wells, with respect to historical data, are not considered to be unusual due to the historical variability of HSR-1 pumping rates and the complex nature of the contaminant distribution and groundwater flow within the former SRA. As first discussed in the 2007 Groundwater Monitoring Report (N.A. Water Systems, 2007b), the more representative indicators of long-term concentration trends in the former SRA are wells MW-12S and MW-13S, at which long-term total VOC concentrations have slowly, but markedly, declined over time (Tables 6 and 7 and Appendix C). The 2018 MW-12S total VOC concentration (227,564 µg/L) decreased with respect to those reported in 2017 (284,105 µg/L) and 2016 (354,367 µg/L), and was more similar to those reported in 2015 (261,450 µg/L) and 2013 (total VOC 255,060 µg/L); however, all of the individual constituent concentrations were lower than historical average concentrations at this well. The 2018 total VOC concentration at MW-13S (6,170 µg/L) increased significantly from those reported in 2017 (876 µg/L), 2016 (1,058 µg/L), 2015 (995 µg/L), 2013 (1,215 µg/L), and 2012 (1,474 µg/L), but remained much lower than historical maximums (Table 6). The 2018 total VOC concentrations in MW-12S and MW-13S (Table 4) were reduced by approximately 65 and 87 percent, respectively, relative to the historical average VOC concentrations at these locations (calculated by summing the average concentrations of individual constituents shown on Table 6). The observed overall concentration reductions are likely the result of a combination of physical and biological remediation processes. HSR-1 has the capacity to lower the water table and increase groundwater flux through deeper portions of the alluvial aquifer. This may locally accelerate rates of contaminant transfer to dissolved phases where they may be detected in groundwater samples and, subsequently, recovered by HSR-1. Additionally, Merck (1998) demonstrated, through laboratory and field studies, that intrinsic bioremediation of VOCs (specifically benzene, toluene, and chlorobenzene) was occurring in alluvial aquifer groundwater in the vicinity of the former SRA.

At most alluvial monitoring locations outside the former SRA, 2018 VOC concentrations were lower than, or similar to, those reported in 2017. The following 2018 results were notable:

- The chloroform concentration at MW-05S decreased from 28 µg/L in 2017 (the highest value reported during the CMI [see Appendix C]) to 4 µg/L in 2018.
- The chlorobenzene concentration at MW-19S (3 µg/L) decreased significantly with respect to 2017 (190 µg/L) and 2016 (110 µg/L) and was the minimum detected value reported at this location.
- Chloroform was detected at well RW-01 at its highest concentration during the CMI (32 µg/L); however it is below the TTHMs MCL (80 µg/L) and is well within historical results at this location (Table 6).

In summary, the 2018 groundwater monitoring data continue to demonstrate broadly decreasing VOC concentrations in the alluvial aquifer during the CMI. Only four individual VOC concentrations exceeded historical averages in the alluvial aquifer, two of which occurred in samples from recovery well HSR-1 and monitoring wells in the former SRA, where concentration fluctuations are common. Outside the former SRA, there were few notable VOC concentrations that increased with respect to 2017 results.

3.1.2 Statistical Comparisons of VOC Data from the Shallow Zone of the Bedrock Aquifer

In approximately 95 percent of 102 comparisons to historical statistics for the shallow zone of the bedrock aquifer (Tables 8 and 9), the 2018 results were lower than or equal to historical averages. This total includes those non-detected results that are shown as ND<Hist on Table 9 (i.e., a non-detected result for given analyte at a given location with an LOQ that was less than an historical detection of that analyte at that location), which represent approximately 53 percent of the comparisons. However, the total does not include non-detected constituents with an LOQ higher than a previous detection at a monitoring location (i.e., non-detected values shown on Table 8 that have blank entries on Table 9). As noted in Section 3.1, three analytes (ethanol, methanol, and trans-1,2-dichloroethene) and four shallow

bedrock wells (MW-10D, MW-15D, MW-17D, and MW-20D) have been removed from the monitoring program beginning in 2015.

There were only five constituents detected at concentrations higher than the historical average concentration at the sampled locations:

- Chlorobenzene detected in the sample from MW-19D (270 μg/L). The reported concentration exceeds the historical average of 239 μg/L and recent previous concentrations (2016 and 2017 were 230 μg/L, 2015 was 260 μg/L) but is within the range of concentrations detected during the CMI (230 μg/L to 300 μg/L) and is equal to the 2013 concentration (270 μg/L).

- Chloroform detected in the sample from monitoring well MW-30D (3 μg/L). The 2018 monitoring well MW-30D chloroform concentration is similar to the previous six monitoring events (3 μg/L in 2017, 3 μg/L in 2016, 4 μg/L in 2015, 3 J μg/L in 2013, 2 J μg/L in 2012, and 1 J μg/L in 2011) and is well below the TTHMs MCL (80 μg/L).

- Chloroform detected in the recovery well RW-1D sample (11 μg/L). This concentration is slightly higher than the average detected concentration of 8.66 μg/L and the highest in CMI (previous highest was 7 μg/L in 2007 and 2003). The concentration is well below the TTHMs MCL (80 μg/L).

- Two constituents detected in the RW-9 sample: cis-1,2-dichloroethene (cis-1,2-DCE, 3 μg/L), and trichloroethene (TCE, 13 μg/L). The cis-1,2-DCE concentration detected in the 2018 monitoring well RW-9 sample (3 μg/L) was the same as the 2017 and 2016 results, similar to the 2015 result (2 μg/L) and is below the MCL (70 μg/L). The TCE concentration detected at recovery well RW-9 (13 μg/L) increased slightly with respect to those detected in 2017 (11 μg/L), 2016 (10 μg/L), 2015 (8 μg/L), and 2013 (2 J μg/L) and is slightly above the TCE MCL (5 μg/L) but is within the historical concentration range for samples from this well (see Table 8).

Otherwise, VOC concentrations reported for most shallow bedrock monitoring and recovery well locations in 2018 were lower than, or similar to, those reported in 2017. Notable exceptions include the following:

- Acetone was detected in the Southside Firehouse well sample (4.6 J μg/L). The result is considered to be suspect and acetone was not detected when the well was resampled in November 2018 (see Table 5). There had been no previous detections of any constituent at this location. Additional information is provided in Section 3.4.

- The 2018 MW-13D TCE concentration (22 μg/L) increased with respect to the concentrations reported in 2017 (7 μg/L, a minimum for this location) and 2013 through 2016 (13 to 14 μg/L). The TCE concentration has decreased significantly since 2011 (950 μg/L). The MW-13D chloroform concentration has fluctuated over the past several years. The 2018 MW-13D chloroform concentration (56 μg/L) increased with respect to the 2017 result (34 μg/L) but was lower than that reported in 2016 (76 μg/L) and similar to that detected in 2015 (52 μg/L). The chloroform concentration is below the historical average concentration at this location (104 μg/L) and the TTHM MCL (80 μg/L).

- The chlorobenzene concentration in the 2018 sample from MW-16D (28,000 µg/L) increased with respect to that reported in 2017 (18,000 µg/L) and was the highest value reported since 2011 (40,000 µg/L, see Appendix C). However, the concentration remained significantly below the historical average concentration at this location (48,914 µg/L, see Tables 8 and 9 and Appendix C).

3.1.3 Statistical Comparisons of VOC Data from the Intermediate-Depth Zone of the Bedrock Aquifer

In more than 90 percent of 30 comparisons to historical statistics for the intermediate-depth zone of the bedrock aquifer (Tables 10 and 11), the 2018 results were lower than or equal to historical averages. This total includes those non-detected results that are shown as ND<Hist on Table 11 (i.e., a non-detected result for given analyte at a given location with an LOQ that was less than an historical detection of that analyte at that location), which represent approximately 33 percent of the comparisons. However, the total does not include non-detected constituents with an LOQ higher than a previous detection at a monitoring location (i.e., non-detected values shown on Table 10 that have blank entries on Table 11). As noted in Section 3.1, three analytes (ethanol, methanol, and trans-1,2-dichloroethene) and three intermediate-depth bedrock wells (MW-08M, MW-14M, and MW-17M) were removed from the monitoring program beginning in 2015.

Total VOC concentrations reported for all intermediate depth monitoring wells except MW-12M were similar to or lower than those reported in 2017. Only three constituents were detected in a sample at concentrations higher than their historical average in the intermediate-depth bedrock zone: benzene and chlorobenzene at well MW-12M and ethyl ether at well MW-25M. None of these detections are consequential. The 2018 benzene concentration at MW-12M (11 µg/L) was the maximum concentration detected at this location but was only slightly higher than the 2017 result (4 µg/L), 2016 result (6 µg/L), the historical average benzene concentration (4 µg/L), and the MCL (5 µg/L). The 2018 MW-12M chlorobenzene concentration (8 µg/L) increased with respect to that detected in 2017 (3 µg/L) and was higher than the historical average concentration (5.23 µg/L, rounded to 5 µg/L in Table 10) but remained well below the MCL (100 µg/L). It is also notable that the MW-12M 1,2-dichloroethane (1,2-DCA) concentration (110 µg/L) increased significantly from that reported in 2017 (56 µg/L) but was below the historical average concentration.

The ethyl ether concentration in the MW-25M sample (150 µg/L) very slightly exceeded the historical average concentration (149.3 µg /l), slightly exceeded the 2017 concentration (130 µg/L) and was equal to the 2016 concentration. The ethyl ether concentration is more than an order of magnitude lower than the cleanup standard (the Pennsylvania Act SHS MSC, revised to 8,300 µg/L in 2016).

As was the case for the nine previous groundwater monitoring events (2017, 2016, 2015, 2013, 2012, 2011, 2010, 2008, and 2007), several constituents are shown in Tables 10 and 11 as being equal to historical minimum detected concentrations or as no longer detected at certain wells (i.e., those shown on Table 11 as ND<Hist). These include 1,2-DCA, acetone, benzene, chloroform, cis-1,2-DCE, methylene chloride and tetrahydrofuran at MW-01M; 1,2-DCA, chloroform, and methylene chloride at MW-03M; toluene at MW-12M; and 1,2-DCA, acetone, benzene, chlorobenzene, and toluene at MW-25M. These data continue

to support the conclusion that there has been a long-term, broadly-based reduction of total VOC concentrations in the intermediate zone of the bedrock aquifer.

3.1.4 Statistical Comparisons of VOC Data from the Deep Zone of the Bedrock Aquifer

Comparisons to historical statistics for the deep zone of the bedrock aquifer are shown in Tables 12 and 13. Approximately 92 percent of the 2018 results were lower than or equal to historical average concentrations. Three constituents were detected in 2018 at concentrations higher than their historical average in the deep bedrock zone, all of which were from the MW-03X sample: chloroform, chloromethane, and ethyl ether. None of these detections are consequential. All the historical data reported for wells MW-02X, MW-03XX, and MW-32X have been collected using the PDB sampling method. The 2018 sample collected from MW-03X represented the eleventh PDB sample in this well. However, despite evidence that the PDB samples from MW-03X yield much higher total VOC concentrations than bailed samples (N.A. Water Systems, 2007a), the results of previous samples collected from MW-03X by other methods were included in the statistical comparisons because they represent a long historical record and were collected under controlled conditions.

The 2018 sample results show that total VOC concentrations in samples from monitoring wells MW-02X, MW-03XX, and MW-32X decreased with respect to 2017 concentrations. The 2018 MW-32X total VOC concentration (332 µg/L and 322.8 µg/L in the primary and field duplicate samples, respectively) decreased significantly with respect to the 2017 results (659.4 µg/L and 660.4 µg/L), 2016 results (1,310.5 µg/L and 1,315.5 µg/L) and 2015 results (15,896 µg/L and 16,069 µg/L), but remained higher than the 2013 results (56 µg/L and 62 µg/L). The total VOC concentrations at MW-32X have fluctuated since the well was first sampled using the PDB sampling method in 2005 (see Table 14). The total VOC concentration increased from 2005 to a maximum in 2010 (109,230 µg/L and 109,210 µg/L in the primary sample and field duplicate samples), then decreased through 2013 to the lowest concentration observed since 2005. The total VOC concentrations increased again until 2015 and have subsequently decreased. The observed variability is interpreted to be the result of changes in the local hydraulic gradients in the vicinity of SWMU 1 (this interpretation is described in more detail in Section 4). As previously noted, the PDB setting depth in MW-32X was the same as that from 2015, approximately 13 feet higher (395 ft bgs) than the depth used in previous events (408 ft bgs). In 2015, the shallower depth was necessitated due to an obstruction that the three PDBs could not be maneuvered past; although the obstruction was removed from the well in June 2015, the same depth has been used since to evaluate whether the higher 2015 concentrations would be repeated.

Total VOC concentrations in PDB samples from deep bedrock wells MW-02X and MW-03XX have decreased over time and are currently at their lowest levels (Tables 12 and 13 and Appendix C). Total VOC concentrations in the MW-02X (14.3 µg/L) and MW-03XX (14,605 µg/L) samples (Table 4) are similar to those reported from 2012 to 2017, and reduced by approximately 87 and 67 percent relative to the historical average VOC concentrations (calculated by summing the average concentrations of individual constituents shown on Table 12). All of the VOC concentrations detected in the MW-02X sample are below their respective groundwater standards (Table 4) and all previously detected constituents in monitoring well MW-02X samples were either equal to their historical minimum concentration (i.e., benzene, ethyl ether) or were not detected in the 2018 PDB samples (Table 12). Individual constituent concentrations detected in MW-03XX were similar to, or lower than, those detected in 2017. However, ELLI reported that the MW-03XX methylene chloride result (11,000 E µg/L) is estimated and qualified with an "E" because the concentration exceeded the instrument calibration range in the diluted analysis using a dilution factor (DF) of 10. A further diluted analysis (DF 100) was performed outside the method holding time from a previously opened container with headspace.

The total VOC concentration reported in the PDB sample collected from MW-03X (5,399,600 µg/L) was higher than the 2017 result, in which several of the detected concentrations were equal to historical minimum detected concentrations. As noted previously, there were three constituents in the 2018 sample that exceeded historical average concentrations (chloroform, chloromethane, and ethyl ether). All the constituent concentrations detected in the MW-03X sample were within their historical range, except for the benzene result, which was equal to the historical minimum. As in previous monitoring events, the principal conclusions derived from these analytical results is that VOC concentrations in the vicinity of MW-03X are relatively high and collectively indicate that DNAPL is present near the well despite there having been no measurable accumulation in the well bore.

3.2 TOTAL VOC PLUME DISTRIBUTION

VOC contour maps showing total NECs in the alluvial aquifer and the shallow monitoring zone of the bedrock aquifer for 2003, 2005, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2015, 2016, 2017, and 2018 are shown in Figures 2 (comprising Figures 2a through 2d) and 3 (comprising Figures 3a through 3d). Because there are relatively few wells with detected VOC concentrations in the intermediate-depth and deep monitoring zones of the bedrock aquifer, a bar chart map was prepared for each zone in lieu of a contour map (see Section 3.3). The NEC contour maps for 2011 through 2015 (shown on Figures 2b, 2c, 3b, and 3c) incorporate the 2011 revisions to site groundwater standards described in Section 2.10 and the 2016 through 2018 maps incorporate the 2016 revisions to the standards. Additionally, the 2015 through 2018 NEC maps incorporate the 2015 revisions to the groundwater monitoring program, comprising the removal of three analytes (methanol, ethanol, and trans-1,2-dichloroethene) and the removal of eight monitoring wells in the alluvium and shallow bedrock aquifers (MW-03S, MW-10S, MW-10D, MW-15D, MW-17D, MW-20D, SW-K01, SW-N01). These modifications have not changed the maps significantly because the removed analytes have been infrequently detected at concentrations exceeding their respective standards, and total VOC NECs calculated for the removed wells have only infrequently exceeded zero (e.g., MW-17D in 2005).

3.2.1 VOC Distribution in the Alluvial Aquifer

The 2018 total NEC map for detected VOCs in the alluvial aquifer (Figure 2d) illustrates that most of the VOCs in the alluvium are concentrated in the former SRA. The density of sampling is also concentrated in this area because nine alluvium monitoring wells (SR-01, SR-03, SR-04, SR-08, MW-12S, MW-13S, MW-24S, SW-0901, and SW-0301) are being used to monitor the effects of source control pumping from horizontal well HSR-1.

The 2018 total VOC NEC map of the alluvial aquifer (Figure 2d) depicts overall stability of the VOC NEC isoconcentration contours relative to the preceding CMI monitoring events (Figures 2a, 2b, and 2c) with some short-term variability over time. The most significant short-term differences from the 2017 map include the following: (1) a significant increase in total VOC NECs at MW-13S in the SRA; (2) significant decreases in total VOC NECs at SR-08 in the former SRA and MW-19S in the northwestern part of the site (i.e., north of the former landfill); (3) a slight increase in the MW-07S VOC NEC concentration; and (4) stable or decreasing total VOC NEC concentrations at all other monitoring locations with non-zero VOC NEC concentrations. Over the long-term, the total VOC NEC maps illustrate the broad decrease of VOC concentrations in the alluvial aquifer during the CMI, which are likely due to the combination of intrinsic bioremediation and the influence of horizontal recovery well HSR-1.

Only one sampled alluvium well outside of the former SRA (MW-07S) had VOC concentrations exceeding a groundwater standard in 2018. All VOC NECs were within historical ranges shown on the maps (i.e., since 2003), although the MW-13S VOC NEC (5,459 µg/L) was the highest since 2003 (9,830 µg/L). Figure 2 shows that the shaded areas representing the VOC NECs are the smallest of any CMI monitoring events. The 2018 MW-19S VOC NEC concentration (0 µg/L) decreased from that reported in 2017 (90 µg/L) due to a significant decrease in the chlorobenzene concentration (from 190 µg/L to 3 µg/L). The MW-19S chlorobenzene and VOC NEC concentrations have fluctuated during the CMI monitoring program, with the highest VOC NEC concentrations shown in 2008 (320 µg/L) and 2010 (320 µg/L) and VOC NECs equal to 0 µg/L reported for six CMI monitoring events (Figure 2 and Appendix C). The 2018 MW-07S total VOC NEC (71 µg/L) was higher than the 2017 VOC NEC (24 µg/L) but is lower that reported for all other CMI monitoring events, due primarily to long-term decreases in benzene and tetrahydrofuran concentrations (Appendix C). The 2018 total NEC VOC concentration at RW-01 (0 µg/L) decreased with respect to the 2017 (20 µg/L) and 2016 values (200 µg/L) because the chlorobenzene concentration decreased (i.e., from 300 µg/L in 2016 to 1 µg/L in 2018). The RW-01 total VOC NEC concentrations have fluctuated during the CMI monitoring program, with a high of 872 µg/L reported in 2006 and values equal to 0 µg/L reported for three CMI monitoring events.

VOC NECs for wells in the vicinity of the former SRA decreased or were similar to those reported in 2017. The highest VOC NEC within the former SRA was reported in the sample from well MW-12S (194,964 µg/L). The MW-12S result was lower than the 2017 (254,262 µg/L) and 2016 (313,255 µg/L) results, but this variability has been typical during the CMI. As previously noted, the MW-13S VOC NEC (5,459 µg/L) was the highest since 2004; this was due primarily to a significant increase in the tetrahydrofuran concentration (from 170 µg/L to 4,900 µg/L). Total VOC NECs at well SR-08 also decreased significantly with respect to 2017 results (from 735 µg/L to 0 µg/L). Concentration fluctuations at the SRA wells, with respect to historical data, are not considered to be unusual due to the historical variability of HSR-1 pumping rates and the complex nature of the contaminant distribution and groundwater flow within the former SRA. The 2018 results may also incorporate some local seasonal variability because sequential events are performed at five quarter intervals.

The 2018 VOC NEC isoconcentration contours in the east-central part of the plant cover a smaller area than the 2017 contours; the change in the shape of the 2018 contours was affected primarily by concentration changes for wells SW-0301, RW-1 and SR-08. As discussed in Section 2.2.2, recovery well RW-1 has not been in operation since November 2004 due to partial collapse of the screened interval. Currently, alluvial groundwater in the vicinity of RW-1 flows toward, and is expected to be intercepted by, horizontal well HSR-1. Although the RW-1 data may reflect some seasonal variability, the relatively low concentrations continue to support previous conclusions that RW-1 is unlikely to be proximal to a residual source of contamination in the alluvial aquifer.

3.2.2 VOC Distribution in the Shallow Zone of the Bedrock Aquifer

As in previous monitoring events, the 2018 total VOC NEC map of the shallow bedrock aquifer (Figure 3d) shows three laterally extended areas of relatively higher concentration associated with SWMUs 1 and 2 and the former SRA. All three areas are elongated roughly parallel to local bedrock layering, which constrains groundwater to flow more readily along the layers than across them. The similarity of this map with those based on prior CMI monitoring events demonstrates that the groundwater contaminant plume is stable with respect to receptors. As in previous events, no VOCs were detected in the East End sentinel wells (MW-23D through MW-27D), with the exception of chloroform (0.09 J µg/L) at MW-26D, which is within the typical range of variability at this location and is well below the TTHMs MCL of 80 µg/L.

For most monitoring locations, a comparison of the 2018 total VOC NEC map of the shallow bedrock aquifer (Figure 3d) with those based on previous CMI monitoring events (Figures 3a and 3b) illustrates overall stability of total VOC NECs, with some localized variability that has changed the general appearance of the map over time. The 2018 VOC NEC are generally similar to those from 2017, with some notable changes that have only slightly affected the contours (e.g., RW-1D, MW-13D, and MW-16D. The 2018 RW-1D VOC NEC (25 µg/L) was lower than the 2013 though 2017 results (range 81 µg/L to 205 µg/L); a 100 µg/L contour was included on the 2013 and 2016 maps, but not needed on the 2015, 2017, and 2018 maps. The 2018 VOC NEC map also shows that the VOC NEC at MW-13D has remained significantly lower than pre-2012 values, the 2018 result (17 µg/L) increased from that reported in 2017 (2 µg/L). The overall decrease at MW-13D is the result of a significant decrease in the TCE concentration from 2011 (950 µg/L) to 2012 (31 µg/L) that reached a low of 7 µg/L in 2017, but then increased in 2018 (22 µg/L). The MW-13D chloroform concentration has remained below the TTHM MCL (80 µg/L) since 2011 but has fluctuated (2018 result 56 µg/L with a range of 25 µg/L to 76 µg/L between 2012 to 2018).

Figures 3b through 3d continue to show that the northwest corner of the former landfill in the western end of the plant is outside the shaded portion of the total VOC NEC map; this is a condition that has existed since 2012 (and also existed from 2005 to 2008) when chlorobenzene concentrations in MW-09D samples were below (or equal to) the MCL (100 µg/L). The 2018 MW-19D chlorobenzene concentration (51 µg/L) decreased with respect to 2017 (100 µg/L) but resulted in no changes to the westernmost VOC NEC contours.

3.3 INDIVIDUAL CONSTITUENT DISTRIBUTION

Bar chart maps were developed for the site COPCs detected in the analyses of the 2018 site monitoring and recovery well samples. The maps, shown in Figures 4 through 8, were prepared for individual constituents in the alluvium, shallow bedrock, intermediate-depth bedrock, and deep bedrock. The constituents depicted in the bar charts and legends on each map are limited to those detected in the depicted aquifer zone. The bar charts are created with a log scale that emphasizes low concentrations to allow all results to be presented. The total VOC concentration (i.e., as distinguished from the total VOC NEC shown on Figures 2 and 3) is also presented on each bar chart. As noted previously, three COPCs presented on certain previous bar chart maps (methanol, ethanol, and trans-1,2-dichloroethene) have been removed from the groundwater monitoring program analyte list beginning with the 2015 monitoring event. Blank spaces have been preserved in the 2018 charts, where needed, so that the color schemes remain consistent with recent preceding maps.

The most frequently detected COPCs sitewide were chlorobenzene and ethyl ether. Some COPCs are rarely detected and are therefore absent from most of the bar charts. Acetonitrile was not detected in any samples; it has been detected only five times since 2003, in samples from MW-12S in 2017 (2,000 J µg/L), 2016 (2,600 µg/L), 2012 (1,500 J µg/L), 2011 (3,000 J µg/L), and 2005 (7,200 J µg/L). Tetrachloroethene and n-hexane were detected in only one sample each, carbon tetrachloride was detected in two samples, and vinyl chloride and chloromethane were each detected only in three primary samples (i.e., not including field duplicates).

3.3.1 VOC Constituents in the Alluvial Aquifer

Figure 4 is a map showing bar charts for selected groundwater samples taken in 2018 from the alluvial aquifer. Figure 5 is a detailed bar chart map showing alluvial aquifer sample results in the vicinity of the former SRA. Several of the former SRA results are only shown on Figure 5, because of the density of data in this area.

Ten wells were sampled in the former SRA vicinity (MW-12S, MW-13S, MW-24S, SR-01, SR-03, SR-04, SR-08, SW-0901, SW-0301, and HSR-1). The following 14 VOC constituents were detected in the former SRA, with most of the constituents being detected in HSR-1 and MW-12S: 1,2-DCA, acetone, benzene, bromobenzene, chlorobenzene, chloroform, cis-1,2-DCE, ethyl ether, n-hexane, methylene chloride, tetrahydrofuran, toluene, TCE, and vinyl chloride. The more common, and significant constituents in terms of total VOC concentrations, are benzene, chlorobenzene, ethyl ether, tetrahydrofuran, and toluene. The lateral extent of the most significant contamination within the former SRA is delineated by the line of SR-series wells and the area is flanked by wells SW-0901 (0 µg/L total VOCs) and MW-24S (313.1 µg/L total VOCs).

The most common and widely distributed VOCs exceeding their respective standards in the alluvial aquifer are chlorobenzene, benzene, and tetrahydrofuran. As shown in Figures 4 and 5, benzene was detected at five locations within the former SRA and at MW-07S at concentrations exceeding its groundwater standard (5 µg/L). Tetrahydrofuran was detected at concentrations exceeding its groundwater standard (26 µg/L) at four locations within the former SRA. Chlorobenzene was detected at concentrations exceeding its standard (100 µg/L) at 6 locations (down from 10 in 2017), including five locations within the former SRA and at monitoring well MW-07S (Figures 4 and 5).

Within the former SRA, benzene concentrations that exceeded the MCL in samples from wells HSR-1, SR-01, SR-03, SR-08, MW-12S, and SW-0301 decreased with respect to the 2017 monitoring event and increased in MW-13S. Tetrahydrofuran concentrations decreased or were similar to 2017 in samples from former SRA wells, except for MW-13S, which increased significantly. Chlorobenzene concentrations decreased at most monitoring locations in the former SRA relative to 2017. The variability of constituent concentrations in the former SRA with respect to the 2017 results is not considered to be unusual due to the complex nature of the contaminant distribution and local changes in groundwater flow paths associated with horizontal well HSR-1 operation. The 2018 results may also incorporate some local seasonal variability.

The 2018 MW-07S benzene (6 μg/L) and tetrahydrofuran (5 J μg/L [below the groundwater standard of 26 μg/L]) concentrations decreased with respect to the 2017 monitoring results (benzene at 19 μg/L and tetrahydrofuran at 22 μg/L) and the 2016 results (benzene 36 μg/L and tetrahydrofuran 72 μg/L); concentrations have been generally decreasing over time. Except for the slight benzene exceedance in the MW-07S sample, neither benzene nor tetrahydrofuran was detected at concentrations exceeding groundwater standard in any alluvial aquifer wells outside the former SRA.

The 2018 chlorobenzene concentrations detected in samples from monitoring locations outside the former SRA in the alluvial aquifer monitoring zone decreased or were similar to 2017 concentrations, except for MW-07S. The 2018 MW-07S chlorobenzene concentration (170 μg/L) increased with respect to that detected in 2017 (110 μg/L) but was within the historical concentration range. Therefore, the chlorobenzene results do not indicate a significant change in the potential risk to downgradient receptors.

As was the case in previous monitoring events, Figures 4 and 5 illustrate that ethyl ether was detected in many alluvium monitoring well samples across the site (12 samples at 11 locations in 2018). Ethyl ether concentrations reported for 2018 were typically similar to, or lower than, those reported in 2017 (except for MW-13S) and all were below the groundwater standard (8,300 μg/L). The concentration in the MW-12S sample (8,200 μg/L) was slightly lower than the 2017 result (8,400 μg/L) and the standard. The variability of the ethyl ether concentrations is interpreted to be related to the operation of well HSR-1.

3.3.2 VOC Constituents in the Shallow Zone of the Bedrock Aquifer

Figure 6 is a map of bar charts for groundwater samples taken in 2018 from monitoring wells and recovery wells the shallow zone of the bedrock aquifer. As described for previous monitoring events, groups of VOC constituents are generally distributed within three areas (although there is some overlap between the groups, particularly with respect to the recovery wells): (1) a north-central area containing the SWMU 1 and former SRA source areas and recovery well RW-4, (2) the area to the east and southeast of the north-central area, including the SWMU 2 source area (the south-centrally located recovery well RW-4 can also be included in this group), and (3) the area west of the north-central area. The most significant total VOC concentrations were detected in monitoring wells MW-12D and MW-16D.

Twelve VOCs were detected in the shallow bedrock monitoring well and recovery well samples: acetone, benzene, carbon tetrachloride, chlorobenzene, chloroform, 1,2-DCA, cis-1,2-dichloroethene, ethyl ether, PCE, tetrahydrofuran, toluene, and TCE. Chlorobenzene and ethyl ether are prevalent and represent the majority of the detected VOC concentrations in the western area and in the north-central portion of the site. As reported in four previous monitoring events, chlorobenzene was detected above its MCL in three areas in the 2018 samples: (1) the vicinity of well MW-19D (270 μg/L), (2) in SWMU 1 recovery well RW-OBS-6 (150 μg/L and 140 μg/L in the primary sample and field duplicate sample, respectively), and (3) in the area including and between wells MW-12D (130 μg/L) and MW-16D (28,000 μg/L), the latter of which increased from that reported in 2017 (18,000 μg/L) and is the highest chlorobenzene concentration in the shallow bedrock aquifer. The chlorobenzene concentration at MW-09D (51 μg/L) decreased from that reported in 2017 (100 µg/L), was higher than those reported in 2012 to 2016 (range of 5 µg/L to 18 µg/L), but remained lower than other historical CMI results (e.g., 160 µg/L in 2011). As in previous CMI monitoring events, the only area where ethyl ether exceeded its Act 2 SHS MSC (8,300 µg/L) in the shallow bedrock aquifer zone during 2018 is the vicinity of MW-12D in the former SRA (8,800 µg/L).

Three additional constituents were detected at concentrations exceeding the relevant groundwater standards in the north-central area: benzene, 1,2-DCA, and tetrahydrofuran. Vinyl chloride, which was detected in one 2017 shallow bedrock sample location (MW-16D, slightly exceeding the MCL), was not detected in the 2018 samples. Benzene was detected in only three shallow bedrock monitoring zone sampling locations in the 2018 monitoring event. As was the case during the 2013 through 2017 monitoring events, the principal area where benzene concentrations exceeded the MCL (5 µg/L) was the north-central portion of the site surrounding MW-12D (10,000 µg/L), MW-16D (76 µg/L), and RW-OBS-6 (88 µg/L and 77 µg/L in the primary sample and field duplicate sample, respectively). The 2018 MW-12D benzene concentration was higher than that reported in 2017 (9,100 µg/L) but lower than the 2012 through 2016 results (range of 11,000 to 19,000 µg/L) and most of the older CMI monitoring data.

1,2-DCA was detected at concentrations that exceeded the MCL (5 µg/L) in the 2018 samples collected from recovery wells RW-4 (18 µg/L) and RW-9 (in the eastern area, 12 µg/L); the RW-4 result was lower than the 2017 sample concentration (31 µg/L), and the RW-9 result was similar to 2017 (11 µg/L). 1,2-DCA was not detected in samples from two locations (RW-OBS-6 and MW-09D) where it had been detected in 2017 below the MCL. Overall, although there has been some variability during the past six monitoring events, 1,2-DCA concentrations in the shallow bedrock (particularly at recovery well RW-4) have decreased during the CMI monitoring program. As shown in Figure 6, tetrahydrofuran was detected only in two locations RW-OBS-6 and MW-12D. The sample from MW-12D (16,000 µg/L) exceeded the Act 2 SHS MSC (26 µg/L), but is similar to results from the past several years.

TCE and chloroform have historically been the principal VOCs in the eastern area. Three of the four TCE detections in shallow bedrock recovery well and monitoring well samples (RW-1D [30 µg/L], RW-9 [12 µg/L] and MW-13D [22 µg/L]) exceeded the TCE MCL (5 µg/L). The RW-1D result was lower than that reported in 2017 (99 µg/L) and is the lowest concentration reported during the CMI. TCE concentrations have decreased overall in samples from MW-13D; the historical range for CMI monitoring events prior to 2012 is 480 µg/L to 1200 µg/L. However, the 2018 TCE concentration in the MW-13D sample (22 µg/L) increased with respect to 2017 (7 µg/L), which is the minimum detected at this location. As was the case in 2016 and 2017, there were no shallow bedrock wells for which the 2018 chloroform concentrations exceeded the MCL (for TTHMs, 80 µg/L). The 2018 MW-13D sample chloroform concentration (56 µg/L) increased with respect to the 2017 result (34 µg/L) but was lower than that reported in 2016 (76 µg/L) and similar to that detected in 2015 (52 µg/L). Chloroform was also detected at low concentrations in samples from recovery well RW-1D (11 µg/L), recovery well RW-2 (3 µg/L), recovery well RW-4 (2 µg/L), recovery well RW-9 (0.6 µg/L), monitoring well MW-26D (0.09 J µg/L), and monitoring well MW-30D (3 µg/L). All of these reported concentrations are similar to previous CMI results except for RW-1D, which is slightly higher than the historical maximum CMI concentration (7 µg/L).

Eight constituents in addition to TCE and chloroform were detected in the eastern area wells (and including RW-4) at low concentrations (acetone, carbon tetrachloride, chlorobenzene, 1,2-DCA, cis-1,2-

DCE, ethyl ether, tetrachloroethene, and toluene), only one of which (1,2-DCA) exceeded its groundwater standard at any eastern area location (in RW-4 and RW-9, discussed above).

3.3.3 VOC Constituents in the Intermediate-Depth Zone of the Bedrock Aquifer

Figure 7 is a map of bar charts for groundwater samples collected in 2018 from the intermediate-depth zone of the bedrock aquifer. Eleven VOC constituents were detected in samples from five wells in 2018. The 2018 results were generally similar to the 2010 through 2017 results and continue to support a broadly-based reduction of VOC concentrations in the intermediate-depth bedrock zone. Benzene, chlorobenzene, ethyl ether, and tetrahydrofuran were detected in three wells, toluene was detected in two wells, and 1,2-DCA, acetone, chloroform, cis-1,2-DCE, methylene chloride, and trichloroethene were each detected in one well.

VOC constituents detected in MW-03M and MW-25M are interpreted to have originated in the SWMU 1 source area. MW-03M, which is more proximal to the source area, has historically had a broader suite of VOC constituents and a higher total VOC concentration. The VOCs detected in MW-01M are interpreted to have originated in shallow source areas proximal to RW-4 and RW-9 (i.e., SWMU 2). The VOCs detected in well MW-12M are interpreted to have originated in the former SRA. Benzene, chlorobenzene, ethyl ether, and tetrahydrofuran were detected in samples from intermediate-depth bedrock wells in both SWMU 1 and SWMU 2 (benzene and chlorobenzene were also detected in well MW-12M). Five constituents (acetone, cis-1,2-DCE, methylene chloride, chloroform and TCE) were detected only in the SMWU 2 related wells. Toluene was only detected in well MW-03M, and 1,2-DCA was detected only in the well associated with the former SRA (MW-12M).

Except for MW-12M, the total VOC concentrations in the 2018 intermediate depth well samples were similar to, or decreased with respect to, 2017 and 2016 results. The 2018 MW-12M total VOC concentration (122 µg/L) increased significantly from that reported in 2017 (63 µg/) primarily due to a higher 2018 1,2-DCA concentration (110 µg/L, compared to 56 µg/L in 2017). The VOC concentration observed at MW-01M in 2018 (41 µg/L) was below the range reported from 2013 to 2017 (54 to 83.9 µg/L). The MW-01M benzene concentration decreased below its MCL to a historical low for this location (1 µg/L) and no other constituents exceeded their respective groundwater standards.

The 2018 total VOC concentration in MW-03M (5,276 µg/L) was slightly lower than those reported from 2015 to 2017 (range 5,613 µg/L to 6,250 µg/L) and higher than the 2013 results (4,000 µg/L primary sample; 3,853 µg/L field duplicate sample). The increase in total VOC concentrations since 2013 is due primarily to higher benzene and chlorobenzene, but other constituents are also somewhat higher. The higher MW-03M VOC concentration may reflect effects of long-term pumping at RW-OBS-6.

The 2018 MW-25M total VOC concentration (630 µg/L) was similar to the 2017 and 2016 total VOC concentration (both 690 µg/L), lower than the 2015 concentrations (800 and 830 µg/L in the primary sample and field duplicate, respectively), and similar to that detected in 2013 (631 µg/L). Benzene has not been detected in MW-25M samples since 2013. The 2018 total VOC concentration in the sample from well MW-31M (7 µg/L) was similar to the 2013 to 2017 results (range 5 to 6 µg/L). Chloroform was the only detected constituent and the concentration (7 µg/L) was below the relevant groundwater standard (TTHM MCL, 80 µg/L).

3.3.4 VOC Constituents in the Deep Zone of the Bedrock Aquifer

Figure 8 is a map of bar graphs for groundwater samples taken in 2017 from the deep zone of the bedrock aquifer. As in previous monitoring events, the 2018 results show that MW-03X had the highest VOC concentrations and greatest number of detected constituents of any of the deep bedrock wells (see Table 4).

As discussed in Section 3.1.4, the 2018 MW-32X sample results (332 µg/L and 319.8 µg/L in the primary and field duplicate samples, respectively) show that total VOC concentrations decreased with respect to the 2017 results (659.4 µg/L and 660.4 µg/L), 2016 results (1,310.5 µg/L and 1,315.5 µg/L) and 2015 results (15,896 µg/L and 16,069 µg/L), but remained higher than the 2013 results (56 µg/L and 62 µg/L). The total VOC concentrations at MW-32X have fluctuated since the well was first sampled using the PDB sampling method in 2005 (see Table 14); the highest VOC concentrations were detected in 2010 (109,230 µg/L and 109,210 µg/L in the primary sample and field duplicate samples). The observed variability is interpreted to be the result of changes in the local hydraulic gradients in the vicinity of SWMU 1 (this interpretation is described in more detail in Section 4). The individual VOCs with the highest detected concentrations in 2018 were benzene (140 µg/L in both the primary and field duplicate samples) and methylene chloride (130 µg/L in the primary sample and 120 in the field duplicate sample). Chlorobenzene, chloroform, chloromethane, cis-1,2-DCE, ethyl ether, toluene, and vinyl chloride were also reliably detected in the MW-32X sample at concentrations below their respective groundwater standards. The observed decrease in the total VOC concentration, like increases and decreases reported in previous years, is interpreted to have resulted from changes of hydraulic gradients in the vicinity of SWMU 1 (see Section 4).

The total VOC concentration reported for the PDB sample collected from MW-03X (5,399,600) µg/L) was higher than, but similar to those detected from 2013 to 2017. As in previous CMI monitoring events, chloroform and methylene chloride were the principal contributors to the high total VOC concentrations at MW-03X. The elevated VOC concentrations at MW-03X are most likely the result of several factors, including the potential presence of residual DNAPL and relatively slow rates of groundwater flow. The groundwater flow rate is limited by the relatively low transmissivity of the deep bedrock aquifer (N.A. Water Systems, 2004), which has reduced the mobility of dissolved phase VOCs and rates of dilution.

The total VOC concentration in the 2018 sample from MW-03XX (14,605 µg/L) decreased with respect to 2017 results (16,515 µg/L) and has followed an overall decreasing trend since the 2005 sample (73,732 µg/L). The sample concentration for methylene chloride (11,000 E µg/L) is considered estimated and was qualified with an "E" because the concentration exceeded the instrument calibration range in the diluted analysis using a dilution factor of 10. A further diluted analysis (dilution factor of 100) was performed outside the method holding time from a previously opened container with headspace (see Section 3.5.8). The VOCs detected in MW-03XX are similar to those detected in monitoring well MW-03X (with the notable exception of chloroform), but the principal constituent concentrations (e.g., methylene chloride and 1,2-DCA) are lower by one to two orders of magnitude.

The 2018 results indicate that the MW-02X total VOC concentrations and individual VOC concentrations are stable or decreasing. The total VOC concentration in MW-02X (15.3 µg/L) was lower than those from

2011 to 2017 (range of 20 µg/L to 51 µg/L) and previous CMI monitoring events (range of 59 µg/L to 312 µg/L). All individual VOCs detected in the 2018 sample were below their respective groundwater standards. Overall, the 2018 analytical results continue to indicate that the main body of the contaminant plume in the deep bedrock continues to be centered in the area of well MW-03X, delineated laterally by MW-02X and MW-32X, and delineated at depth by MW-03XX.

3.4 MUNICIPAL GARAGE AND SOUTHSIDE FIREHOUSE ANALYTICAL RESULTS

Table 5 shows the results of samples from the Municipal Garage and Southside Firehouse wells and the associated QA/QC samples. There was one constituent, acetone (4.6 J µg/L), detected in the Southside Firehouse well sample. Although this result is reported, it is considered to be suspect for the following reasons: (1) acetone is a typical laboratory contaminant, (2) acetone had never been detected in samples collected at this location (nor had any other constituent), and (3) acetone was detected in a trip blank that, although not directly associated with the Firehouse sample, was submitted to the laboratory at the same time. The Firehouse well was resampled on November 1, 2018 and acetone was not detected (see Table 5). Chloroform was detected at low concentration below the reporting limit (0.5 µg/L) in both the primary sample (0.1 JB µg/L) and the field duplicate (0.2 JB µg/L). However, chloroform was also detected in the associated field blank (FB-1) at a higher concentration (1 µg/L). The detections in the sample and field duplicate were qualified with a "B" due to blank contamination and are considered non-detected. It is also noted that chloroform was detected in the original field blank sample FB-3 (0.4 J µg/L) collected on October 2, 2018.

There were no constituents detected in the primary and duplicate samples from the Municipal Garage well during 2018. This result is the same as those reported in 2017 and 2016 and similar to that reported in 2015, where chloroform, PCE, and TCE were detected, but at very low concentrations (all results 0.2 J µg/L) below the laboratory LOQ (0.5 µg/L). The Municipal Garage well is not used by employees for drinking water and is the nearest water supply well to monitoring well MW-26D, which had a very low chloroform concentration (0.09 J µg/L) detected during the 2018 monitoring event.

3.5 QUALITY ASSURANCE/CONTROL DATA FOR GROUNDWATER VOC ANALYSES

Tables 4 and 5 summarize the analytical results of the groundwater monitoring samples, including the blanks and blind duplicate samples submitted to the laboratory. Appendix D contains the analytical data packages provided by the laboratory. Hatch utilized the QA/QC samples described in Section 2.8 and laboratory-provided information to review analytical data for quality-assurance purposes. The results of the review are summarized in the following sections.

3.5.1 Trip Blank and Field Blank Analyses for VOCs

Trip blanks were prepared by ELLI and accompanied samples from the time of their collection until they were transported to the laboratory for analysis. Only dedicated or disposable sampling equipment was used; therefore, all but one of the VOC field/equipment blanks were prepared in the field by pouring laboratory-supplied analyte-free water into sample vials at monitoring locations. For the PDB sampling method, a field blank was prepared using an unopened PDB that was kept by the sampling personnel during sampling activities. VOC trip blanks and field/equipment blanks were analyzed for the COPCs identified in Section 2.1.2. There were six field blanks and eight trip blanks collected during the event, including one of each collected during the resampling of the Southside Firehouse well. Low constituent concentrations were detected in two of the eight trip blanks and in five of the six field blanks (Tables 4 and 5). The detections and any required qualifiers are summarized as follows:

- For laboratory sample delivery group (SDG) DVC82, field blank FB-3 had detection of chloroform (0.4 J µg/L) and TB-3 had a detection of chloromethane (0.1 µg/L). There were no detections of these constituents in their respective associated samples; therefore, no data were qualified.
- For SDG DVC84, trip blank TB-1 had a detection of acetone (0.9 J µg/L) and field blank FB-2 had a detection of chloroform (0.2 J µg/L) and toluene (0.06 µg/L). There were no detections of these constituents in their respective associated samples; therefore, no data were qualified.
- For SDG DVC85, field blank FB-4 had a detection of chloroform (0.3 J µg/L). Chloroform was detected at similar concentrations in two associated samples (MW-19S [0.2 JB µg/L] and SR-04 [0.2 JB µg/L]). Both results were qualified with a "B" to indicate blank contamination and are considered non-detected results (e.g., including total VOC calculations or statistical calculations).
- For SDG DVC86, field blank FB-5 (collected from a passive diffusion bag that was not deployed and was stored during the sampling event) had an acetone detection (3 J µg/L). Acetone was detected at similar concentrations in four associated samples: MW-02X (1 JB µg /l), MW-03XX (2 JB µg/L), MW-32X (3 JB µg/L), and MW-39X (field duplicate sample of MW-32X, 3 JB µg/L). These results were qualified with a "B" to indicate blank contamination and are considered non-detected results.
- For SDG DVC87, chloroform was detected at low concentration in field blank FB-1 (1 J µg/L). As described in Section 3.4, chloroform was also detected in a sample (0.1 JB µg/L) and field duplicate sample (0.2 JB µg/L) from the Southside Firehouse. These samples were qualified with a "B" due to blank contamination and are considered non-detected.

3.5.2 Field Duplicate Sample Analyses for VOCs

Blind duplicate samples were collected for VOC analysis from the following monitoring locations: MW-23D, MW-32X, RW-OBS-6, SR-01, the Municipal Garage well, and the Southside Firehouse (resampling) (Tables 4 and 5). Analytes detected in these samples were detected in both the primary and duplicate samples, with the following exception: the analyte 1,2-DCA was detected in the primary sample from SR-01 (17 J µg/L) and was below the quantitation limit in the field duplicate sample (MW-60S, < 5 UJ µg/L). A relative percent difference (RPD) of 25 percent between constituent concentrations in the primary and duplicate samples was used as the basis for evaluating the field duplicate results. All results were within 25 percent RPD except for the previously mentioned 1,2-DCA results from SR-01 and the cis-1,2-DCE results from the RW-OBS-6 primary sample (0.4 µg/L and field duplicate [0.3 µg/L]), the latter of which were not qualified because they were essentially equal. The SR-01 1,2-DCA results were qualified as follows: the detected result (sample SR-01) was qualified as estimated with a "J", and the non-detected value (duplicate sample MW-60S) was qualified with a "UJ" to indicate that the constituent was not detected but the quantitation limit is estimated. No additional 1,2-DCA results in SDG DVC85 were qualified, because the detected 1,2-DCA concentration was small compared to the total VOCs in the SR-01 sample (5,473.3 µg/L).

3.5.3 Matrix Spike/Matrix Spike Duplicate Analyses For VOCs

The samples from the following wells were submitted for analysis as MS/MSD samples for the target COPCs (i.e., selected VOCs): the Southside Firehouse (identified as SSFH), monitoring wells MW-23D, SW-0402, MW-12M, and SR-03. Summaries of the results of site-related sample MS/MSD analyses are presented in the laboratory analytical data packages in Appendix D. For samples that were run in batches that did not include site-specific MS/MSDs, the laboratory analyzed laboratory control samples (LCSs).

The data packages show that the analytical results for the MS/MSDs for the target compounds were within the laboratory-specified recovery criteria, with the exceptions noted below:

- For laboratory SDG DVC82 and the spiked sample collected from the Southside Firehouse well, the MS and/or MSD percent recoveries for multiple analytes were outside the QC limits (sec-butylbenzene, tert-butylbenzene, 1,1-dichloroethene, hexachlorobutadiene and ethyl acetate). Only one compound, ethyl acetate, was below the acceptance window (it had 69 percent recovery in the MS and 66 percent in the MSD, the latter was slightly below the lower recovery limit of 67 percent), and the RPD was also outside QC limits. Ethyl acetate was not detected in any samples and has not been detected in any associated samples during the historical reporting period. All other compounds were above the acceptance window and were not detected in any samples. Therefore, no data qualifications were made based on the results of this MS/MSD pair.
- For laboratory SDG DVC84 and the spiked sample collected from SW-0402 the MS and/or MSD percent recoveries for a few analytes exceeded the QC limits, indicating a potential positive bias: 1,2-DCA, carbon tetrachloride, chloroform, TCE, and PCE. The LCS recovery for these parameters was within the acceptance window and all detected sample concentrations in associated samples were below the relevant groundwater standards. Therefore, no data qualifications were made based on the results of this MS/MSD pair.
- For laboratory SDG DVC85 and the spiked sample collected from MW-12M, the MS and/or MSD percent recoveries for a few analytes exceeded the QC limits, indicating a potential positive bias. chloroform, carbon tetrachloride, and PCE. The LCS recoveries for these parameters were within the acceptance window and none of these compounds were detected in the associated samples. Therefore, no data qualifications were made based on the results of this MS/MSD pair.
- For laboratory SDG DVC86 and the spiked sample collected from SR-03, the MS and/or MSD percent recoveries for the following analytes were outside QC limits: benzene, TCE, chlorobenzene, 1,2-DCA, carbon tetrachloride, and ethyl ether. The LCS recoveries for these parameters were within the acceptance window. No data qualifications were made for benzene, chlorobenzene, and ethyl ether because the unspiked sample results are greater than four times the spike added. No data qualifications were made for TCE and carbon tetrachloride because

the recoveries exceeded the recovery limits and there were no detections in the associated samples. One data qualification was made related to the MS/MSD for 1,2-DCA: the detected concentration in the associated HSR-1 sample was qualified with a "J" as estimated because the MS/MSD recoveries exceeded the recovery limits indicating a high bias, the LCS recovery was equal to high recovery limit, and the detected result (11 µg/L) only slightly exceeded the MCL (5 µg/L).

3.5.4 Surrogate Recovery Analyses for VOCs

ELLI reported that the surrogate recoveries for SW-846 Method 8260B and EPA Method 524.2 VOC analyses were all within QC criteria. No data qualifications were required.

3.5.5 Laboratory Control Samples for VOCs

ELLI reported that the LCS and LCSD results were within the applicable laboratory QA/QC limits for target compounds, with the exception of the following:

- For laboratory SDG DVC82, the LCS recovery for ethyl ether (68 percent was slightly below the LCS acceptance window [72-121 percent]). Ethyl ether was not detected in any samples and has not been historically detected in any samples from the associated locations. The associated non-detected results (samples TB-3, MW-25D, MW-24D, MW-27D) have been qualified as "UJ" (Table 4) indicating that the compound was not detected but the detection limit is estimated. This data qualifier also applied to data associated with SDGs DVC83 (sample MW-23D) and DVC84 (samples MW-26D, MW-51D [duplicate of MW-23D], and FB-2).
- For laboratory SDG DVC86: the LCS recovery for chloroform (121 percent) slightly exceeded the LCS acceptance window (80-120 percent). Chloroform was only detected in one associated sample (HSR-1 at 3 µg/L). This result has been qualified with a "J" as estimated.

3.5.6 Method Blanks for VOCs

ELLI reported that there were no analytes detected in any of the method blanks in the six data packages; therefore, no data were qualified based on method blank analyses.

3.5.7 Holding Times

ELLI reported that all VOC analyses were conducted within the method required holding times, except for the confirmation analyses described in Section 3.5.8.

3.5.8 Other QA/QC Information

ELLI reported that the following additional QA/QC information:

- For SDG DVC85, the MW-08D ethyl ether result (750 E µg/L) is estimated because the concentration exceeded the instrument calibration range using a dilution factor of five. The laboratory reported that a further diluted analysis (dilution factor of 10) was performed from a previously opened container with headspace and/or outside of the method holding time that confirmed the initial analysis. The laboratory qualified the result with an "E" to indicate the calibration range exceedance.

- For SDG DVC86, the MW-03XX methylene chloride result (11,000 E μg/L) is estimated because the concentration exceeded the instrument calibration range in the diluted analysis using a dilution factor of 10. A further diluted analysis (dilution factor of 100) was performed outside the method holding time from a previously opened container with headspace. The laboratory qualified the result with an "E" to indicate the calibration range exceedance.

SECTION 4
WATER LEVEL MONITORING RESULTS

A primary function of the recovery well systems is to maintain hydraulic control of the residual source areas in the alluvium of the SRA and in the shallow bedrock aquifers within the SWMU 1 and 2 boundaries. Site-wide water-level monitoring is used to document the directions of hydraulic gradients in the alluvial and bedrock aquifers and to estimate the extent of hydraulic capture. These hydraulic control evaluations are conducted concurrently with the groundwater sampling events, at a frequency of once every five calendar quarters. If water-level measurements indicate that hydraulic control of the residual source areas has been compromised in a manner and degree that conflicts with remedial objectives (i.e., progress toward remedial goals), then modifications to the remedy will be considered as necessary to ensure consistency with risk assessment assumptions and progress towards the overall remedy objective.

Table 15 provides the site-wide water level data collected on September 27, 2018 during the Fourth Quarter 2018 monitoring event. Appendix F provides quarterly water level elevation data collected since the Third Quarter 2017 monitoring event. Figures 9 through 12 are contour maps of piezometric surface elevations in the alluvial aquifer, the former SRA of the alluvial aquifer, and the shallow and intermediate-depth zones of the bedrock aquifer, based on well water levels measured on September 27, 2018.

Groundwater flows from regions of higher head to regions of lower head. The direction of groundwater flow is also influenced by the hydraulic properties of the medium through which it flows. The geometry of sedimentary rock layers (bedding) in the bedrock aquifer exerts such an influence by accommodating flow more readily along layers than across them. The horizontal alignment (strike) of layers in the bedrock aquifer is 75 degrees east of true north. Groundwater in the bedrock aquifer tends to flow from the interior of the site toward the river in directions parallel to these rock layers (Figure 11). In contrast, flow in the alluvial aquifer is not so constrained and tends to flow to the river along pathways roughly perpendicular to the contour lines shown in Figure 9.

The piezometric surfaces depicted in Figures 9 through 12 share several general characteristics. The surfaces descend from areas of higher ground elevation in the central portion of the site and from the south toward the river. This imparts a roughly radial aspect to the lines of equal piezometric elevation (head). The piezometric elevation at any point is the elevation that the water would rise to in a piezometer having a screen open to the level of the aquifer depicted in the maps.

The piezometric contours in the vicinity of the former SRA of the alluvial aquifer and the shallow bedrock aquifer are locally perturbed by the influence of pumped recovery wells. This is most obvious in the piezometric surface of the shallow bedrock aquifer (Figure 11), where the influences of recovery wells RW-1D, RW-4, RW-9, and RW-OBS-6 are evidenced by closed depressions (cones of depression) around those wells. As reported previously, the influence of recovery well RW-2 is not substantial (Chester Engineers, 2011).

The interpreted combined capture zone of wells RW-OBS-6, RW-9, RW-4, and RW-1D shown in Figure 11 demonstrates the capacity of these recovery wells to capture groundwater contaminants in the SWMU 1 and SWMU 2 source areas. The SWMU 1 source area is encompassed by the capture due to the influence of RW-OBS-6 (primarily) and RW-2; the SWMU 2 source area is encompassed by the influence of recovery wells RW-4, RW-1D, and RW-9.

A closed depression can also be seen in Figure 10 in the piezometric surface surrounding the screened interval of horizontal recovery well HSR-1, indicating the pumping influence of horizontal recovery well HSR-1 in the alluvial aquifer near the former SRA. Figures 9 and 10 show the September 27, 2018 water levels near recovery well HSR-1. Sitewide water levels in the alluvial aquifer in September 2018, were broadly higher than those in August 2017. However, the extents of the capture zone surrounding HSR-1 for both periods are similar.

The September 27, 2018, piezometric surface map for the intermediate-depth bedrock zone is shown in Figure 12. The piezometric surface contour pattern shown is similar to that in August 2017; however, the 2018 water levels were mostly higher in September 2018 than those in August 2017.

Figure 13 depicts the September 27, 2018, piezometric surface on a plane inclined at roughly 40 degrees (parallel to local bedding), which intersects the open intervals of monitoring wells MW-32X, MW-03X, MW-02X, MW-03XX, as well as intermediate-depth and shallow bedrock monitoring wells screened in the roughly the same stratigraphic interval. Therefore, the figure depicts piezometric heads on an inclined layer that passes through all three bedrock monitoring zones. The inclined zone represented in Figure 13 has been determined to be a preferential pathway of VOC transport from SWMU 1. As such, it was the target of a deep bedrock investigation that included the installation of wells MW-02X, MW-32X, and MW-03XX in late 2003 and early 2004. The piezometric heads are of interest, because they define hydraulic gradients that direct groundwater flow and contaminant transport directions.

The September 27, 2018, head measurements depicted in Figure 13 are similar to those from the 2007 through 2017 monitoring events in that the OBS-5 head is higher than those at MW-32X and MW-03M. The opposite was observed in 2005 and 2006, where the MW-32X and MW-03M heads were higher than that of OBS-5. The likely causes of the observed changes are the following factors that affect local hydraulic gradients: (1) the long-term effects of pumping recovery well pumping RW-OBS-6 and (2) shifts in the position of the bedrock groundwater divide that lies near SWMU 1. As depicted in Figure 13, there is a stagnation point or dynamic hydraulic divide near well OBS-5. This divide separates flow up-dip toward RW-OBS-6 from down-dip flow, which may be directed locally from south-southwest to southeast. As it is a dynamic divide, shifts of its position may be responsible for localized changes of hydraulic gradients and flow directions. This, in combination with a significant VOC concentration gradient (e.g., between wells OBS-5 and MW-32X) is interpreted as the likely cause of noted VOC concentration increases at well MW-32X (Sections 3.1.4 and 3.3.4) that occurred from 2006 to 2010 and from 2013 to 2015, as well as the decreases reported during the 2011, 2012, 2013, 2016, 2017, and 2018 events.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been drawn from the data:

1. Comparison of the 2018 groundwater analytical data with historical sampling results demonstrates that the extent of groundwater contamination and the general disposition of VOC concentrations within the site have remained similar between successive CMI sampling events, while broadly reduced during the Corrective Action project. These results indicate that, despite some constituent concentration fluctuations, the contaminant plume in the alluvial and bedrock aquifers is stable with respect to downgradient receptors; engineering controls and hydrogeologic constraints on groundwater flow pathways are preventing exposure to groundwater contaminants at levels above drinking water standards or that might pose unacceptable risk.

2. There were no constituents detected in the primary and duplicate samples from the Municipal Garage well during 2018. This is consistent with historical data.

3. The detection of a low concentration of acetone (4.6 J µg/L) in the October 2, 2018, sample from the Southside Firehouse well is considered suspect. Acetone is a typical laboratory contaminant that has never been detected in samples collected at this location (nor has any other constituent). Additionally, acetone was detected in a trip blank that, although not directly associated with the Firehouse sample, was submitted to the laboratory at the same time. The Firehouse well was resampled on November 1, 2018, and acetone was not detected (at a reporting limit of 5 µg/L) in either the primary sample or a field duplicate. Chloroform was detected at low concentrations below the reporting limit (0.5 µg/L) in both the November 1 primary (0.1 JB µg/L) and duplicate samples (0.2 JB µg/L); however, chloroform was also detected in the associated field blank (FB-1) at a higher concentration (1 µg/L). The detections in the sample and field duplicate were qualified with a "B" due to blank contamination and are considered non-detected. It is also noted that chloroform was detected in the original field blank sample FB-3 (0.4 J µg/L) collected on October 2.

4. VOC concentrations were generally similar to, or lower than those reported in 2017. Notable exceptions included the following: (1) increased TCE and chloroform concentrations in the MW-13D sample, (2) higher individual constituent and total VOC concentrations in MW-03X, (3) increased tetrahydrofuran and total VOC concentrations at monitoring well MW-13S, and (4) increases in the chlorobenzene concentrations at monitoring wells MW-07S, MW-16D, and MW-19D. Observed variability in the 2018 former SRA alluvium monitoring well sample VOC concentrations, relative to 2017, was likely related to local changes in groundwater flow paths due to the influence of horizontal well HSR-1. The 2018 results may incorporate some local seasonal variability.

5. There were several individual constituent concentrations detected in 2018 that exceeded historical average concentrations. Most of these results represented insignificant changes relative to other recent data or low detected concentrations below groundwater standards.

6. The 2018 TCE concentration in the MW-13D sample (22 µg/L) increased slightly with respect to the 2017 result (7 µg/L, the historical low concentration) but remains significantly lower than pre-2012 historical results. The MW-13D sample chloroform concentration (56 µg/L) also increased with respect to the 2017 result (34 µg/L) but was lower than that reported in 2016 (76 µg/L) and similar to that detected in 2015 (52 µg/L).

7. The main body of the contaminant plume in the deep zone of the bedrock aquifer continues to be centered in the area of well MW-03X, delineated laterally by MW-02X and MW-32X, and delineated at depth by MW-03XX. All of the VOC concentrations detected in the MW-02X sample were below their respective groundwater standards. VOC concentrations in deep bedrock aquifer monitoring well MW-32X continued to decrease relative to the significant increase reported in 2015. The cause of the decrease is interpreted to be changes of hydraulic gradients in the vicinity of SWMU 1 that result in a local change in subsurface distribution of dissolved VOCs.

8. As in previous monitoring events, the 2018 total VOC NEC map of the shallow bedrock aquifer (Figure 3d) shows three laterally extended areas of relatively higher concentration associated with SWMUs 1 and 2 and the former SRA. All three areas are elongated roughly parallel to local bedrock layering, which constrains groundwater to flow more readily along the layers than across them. The similarity of this map with those based on prior CMI monitoring events demonstrates that the groundwater contaminant plume (i.e., VOC concentrations exceeding groundwater standards) is stable with respect to receptors.

9. As described in previous CMI groundwater monitoring reports, the concentrations of total VOCs and individual VOC constituents were broadly lower in 2018 relative to long-term historical average VOC concentrations. This is the case for approximately 97 percent of sample results in the alluvial aquifer, approximately 95 percent of sample results in the shallow bedrock aquifer, approximately 90 percent of results in the intermediate-depth bedrock aquifer, and approximately 92 percent of results in the deep bedrock aquifer. These data provide evidence that there has been a long-term, broadly-based reduction of VOC constituent concentrations in most areas of the site.

10. Site-wide water levels in all aquifer zones were broadly higher in 2018 than in 2017. However, the estimated capture zone extents for the associated recovery wells in the alluvial and shallow bedrock aquifers were similar in both periods.

11. The current CMI monitoring network outlined in the CMI groundwater field sampling plan provides adequate plume delineation in each of the aquifer monitoring zones.

Based on the information presented in the report, the following recommendations have been made:

1. The Danville Area School District is not using the Riverside Elementary School for classes during the 2018-2019 school year. The field sampling plan indicates that the well should be sampled

when school is in session, but the well was unavailable to be sampled during the 2018 monitoring event. However, the school well should be retained as a potential sampling location should the school be used again in the future.

2. During 2015, the MW-32X PDB samplers were set approximately 13 feet higher than other recent previous monitoring events due to an obstruction in the well. The 2015 VOC concentrations were significantly higher than those reported in 2013. The obstruction was removed in June 2015; however, during 2017 the PDBs were set at the same depth as 2015 and 2016 to evaluate whether depth was the source of the higher concentrations. The 2018 MW-32X VOC concentrations decreased with respect to those reported in 2015, 2016, and 2017 but remained higher than the very low concentrations those reported in 2013. Therefore, it is recommended that the current PDB setting depth continue to be used during the next five-quarter sampling event (i.e., first quarter 2020).

SECTION 6
CMI PROGRESS REPORT

6.1 CMI ACTIVITIES COMPLETED

The following CMI activities were completed during the October 1, 2017, to December 31, 2018, monitoring period.

- Cherokee Pharmaceuticals submitted the *Third Quarter 2017 CMI Groundwater Monitoring and Progress Report* to EPA and PADEP in January 2018.
- There have been no formal well installation or alteration activity reviews during this reporting period, however Cherokee Pharmaceuticals has been monitoring recent property development to the south of the plant along Sunbury Road. The Borough of Riverside adopted an ordinance in 2013 (in Appendix G of Chester Engineers, 2014a) that requires local well drillers to submit a notification to the Borough at least 15 days prior to commencing any well drilling or well alteration activity. Cherokee reviews information related to any new well construction or alteration provided by the Borough. Cherokee Pharmaceuticals also periodically sends reminders to local well drillers with regard to the requirements of the ordinance.
- Cherokee Pharmaceuticals performed routine cutting/mowing to manage Japanese knotweed (*Fallopia japonica*) on the slope areas of Zone 5 landfill cover. Japanese knotweed is no longer considered a significant risk to cover integrity.
- Cherokee Pharmaceuticals performed annual inspections of the landfill cover during November 2017 and November 2018. The remedy is performing effectively. There were no significant issues noted with respect to the landfill cover, including the cover soils/aggregate and stormwater management components.
- The 2018 CMI groundwater monitoring event occurred between September 27, 2018, and November 1, 2018.
- The condition of the monitoring well network was reviewed during the September 2018 quarterly CMI water level monitoring event. No new significant issues were identified. A few issues related to well identification (such as missing or detached identification tags) have been, or will be, addressed. More substantial repairs, such as repairs of cracked concrete well pads, will be made if it is determined that sample integrity is likely to be compromised.
- Cherokee and Hatch performed regular O&M inspections of the groundwater recovery well system. Inspection records and field notes are used to periodically evaluate the frequency of pumping system cleaning through review of maintenance records. Recovery well flow meter calibration is performed two times per year (with limited exceptions [e.g., if a well is out-of-service during the calibration]).
- Cherokee Pharmaceuticals has continued the practice of well disinfection with sodium hypochlorite (household bleach; i.e., the commonly practiced "well shocking") as an alternative

well maintenance/rehabilitation method to reduce maintenance costs and reduce down-time and variable well performance (Chester Engineers, 2016a). This procedure was utilized at RW-4 during this reporting period.

6.2 CHANGES MADE TO THE REMEDY

There have been no significant changes to the remedy during this reporting period.

6.3 RECOMMENDATIONS FOR REMEDY MODIFICATIONS

Recommendations for remedy modifications are detailed in the 2019 CMI Five-Year Re-Evaluation Report, October 2013 – October 2018 (Hatch, 2019), and are summarized below:

- With approval from EPA and PADEP, optimize the CMI groundwater monitoring program including the removal of seven groundwater monitoring locations (MW-05S, MW-09S, SW-0402, SW-0901, SW-Q01, MW-08D, and MW-09D).
- With approval from EPA and PADEP, eliminate the requirement for landfill remedy groundwater evaluation (i.e. effect of cap on groundwater contaminant concentrations within the landfill vicinity).

The following legacy recommendations remain from previous reporting periods.

- Evaluate the position and condition of monitoring and former domestic wells that are no longer used for monitoring and, if warranted, propose a list of wells for abandonment.
- Evaluate the potential use of Alternate Concentration Limits (ACLs).

6.4 PROJECTED ACTIVITIES FOR THE NEXT REPORTING PERIOD

The following activities are anticipated to occur during the next reporting period (i.e. January 1, 2019, through March 31, 2020):

- CMI groundwater monitoring will be conducted during the first quarter of 2020. Water level monitoring will be performed quarterly.
- The landfill cover inspection will be performed during November 2019.
- Cherokee Pharmaceuticals is currently evaluating options for well reconstruction to stabilize the borehole at RW-2.
- As described in the CMI Five-Year Re-Evaluation Report, October 2013 – October 2018 (Hatch, 2019), begin a review of current aqueous and non-aqueous phase constituent spatial distributions and concentrations in the context of horizontal and vertical proximity to buildings and potential preferential pathways. A soil gas investigation plan will be developed and implemented, if required, based on the review of existing site conditions and recent data.

SECTION 7
REFERENCES

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